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EFFECTS OF CANOPY GEOMETRY AND CLOTH PERMEABILITY ON THE DRAG COEFFICIENT OF A CROSS PARACHUTE IN THE FULLY OPEN AND REEFED CONDITIONS FOR A W/L RATIO OF 0.3

BY W. P. LUDTKE

UNDERWATER SYSTEMS DEPARTMENT

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This report describes a series of wind-tunnel tests on the cross-type parachute to investigate the effects of cloth permeability, number of suspension lines, and suspension line length in the fully opened and reefed conditions. Forty-inch-diameter models with a canopy arm width-to-length ratio (W/L) of 0.3 were tested at various velocities from 50 fps to 293 fps in the fully inflated state. Results of these tests demonstrate that the parachute geometry and cloth permeability do have an effect on the drag capability of the cross parachute. Additional tests of reefed configurations for several reefing line

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lengths-to-canopy-diameter ratios from 0.6 to 1.6 at a constant velocity of 203 fps established the reefed characteristics of this parachute. The steady state forces in the reefing line were measured by use of strain gage links. Data are presented in tabular and graphical format. Photographs of representative canopy shapes are included for illustration.

FOREWORD

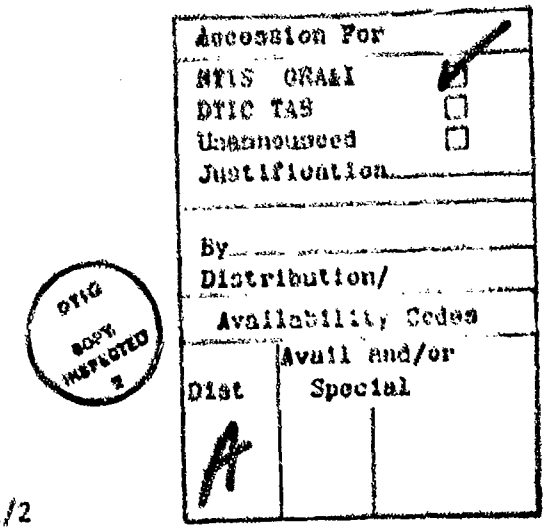
This report describes a series of wind-tunnel tests on the cross-type parachute to investigate the effects of cloth permeability, number of suspension lines, and suspension line length in the fully opened and reefed conditions. Forty-inch-diameter models with a canopy arm width-to-length ratio (W/L) of 0.3 were tested at various velocities from 50 fps to 293 fps in the fully inflated state. Results of these tests demonstrate that the parachute geometry and cloth permeability do have an effect on the drag capability of the cross parachute. Additional tests of reefed configurations for several reefing line lengths-to-canopy-diameter ratios from 0.6 to 1.6 at a constant velocity of 293 fps established the reefed characteristics of this parachute. The steady state forces in the reefing line were measured by use of strain g. links. Data are presented in tabular and graphical format. Photographs of representative canopy shapes are included for illustration.

These tests were conducted in the University of Maryland Subsonic Wind Tunnel at College Park, Maryland.

The investigation presented in this report is related to the improvement of parachute technology.

The effort was accepted under an Independent Exploratory Development Assignment (IED).

GEORGE P. KALAF
By direction



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ILLUSTRATIONS (Cont.)

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INTRODUCTION

The Naval Surface Weapons Center has pursued Cross type parachutes in a number of low altitude weapons systems in the subsonic through transonic velocity range, and also for meteorological high altitude (100,000 to 318,000 feet) probes. Cross type parachutes have demonstrated excellent reliability, parachute stability and two body stability, and have resulted in a unit cost reduction. Drag coefficient and canopy hem reefed data were published in reference 1 for a canopy W/L=0.264.

During developments we have, upon occasion, encountered a "critical velocity" effect with a 0.264 ratio canopy. The canopy would not completely inflate or would finish the inflation process very slowly. One approach to this problem was to modify the W/L ratio to 0.3. Our flight test experience has demonstrated that the 0.3 ratio improved the inflation characteristics, but at the expense of apparently degraded two body stability.

Skirt hem reefed Cross parachutes complete inflation rapidly at disreef. A purpose of this test series is to ascertain whether a reefing line located at some place along the reinforcement tape other than the hem will provide a more favorable reefed canopy inflated shape.

[1] Ludtke, W., "Effects of Canopy Geometry on the Drag Coefficient of a Cross Parachute in the Fully Open and Reefed Conditions for a W/L Ratio of 0.264," NOLTR 71-111, 20 Aug 1971.

APPROACH

PARACHUTE MODELS. Three series of Cross Parachute models were designed using a canopy cloth of different air permeability for each series. All models consisted of two panels 40 inches in length with a W/L=0.3. The two panels were arranged to form the configurations illustrated in Figure 1. Each model series consisted of a total of nine parachutes for the same canopy cloth. The canopies were configured for 12, 16, or 24 suspension lines, and each canopy suspension line configuration was completed with suspension line lengths of 1.0, 1.4, or 1.6 canopy diameters. The actual suspension lines were shortened a specified length so that the apparent line length in the fully inflated configuration was 1.0, 1.4, or 1.6 diameters when mounted on the parachute mounting ring. This approach provided 27 possible geometric configurations for drag coefficient studies. The materials used in the model parachute constructions are listed in Table 1 and construction details are shown in Figure 2. Reefing rings were installed at two locations on the canopy tape reinforcements as shown in Figures 2 and 3. These locations placed the reefing rings at 25% and 50% of the distance from the canopy hem to the edge of the adjacent parachute panel. Due to limited wind tunnel testing time initial tests were conducted on each reefing ring location. The reefing ring nearest the canopy hem appeared to best meet the test objective and was selected for further tests. Twenty-seven reefed parachute configurations were tested.

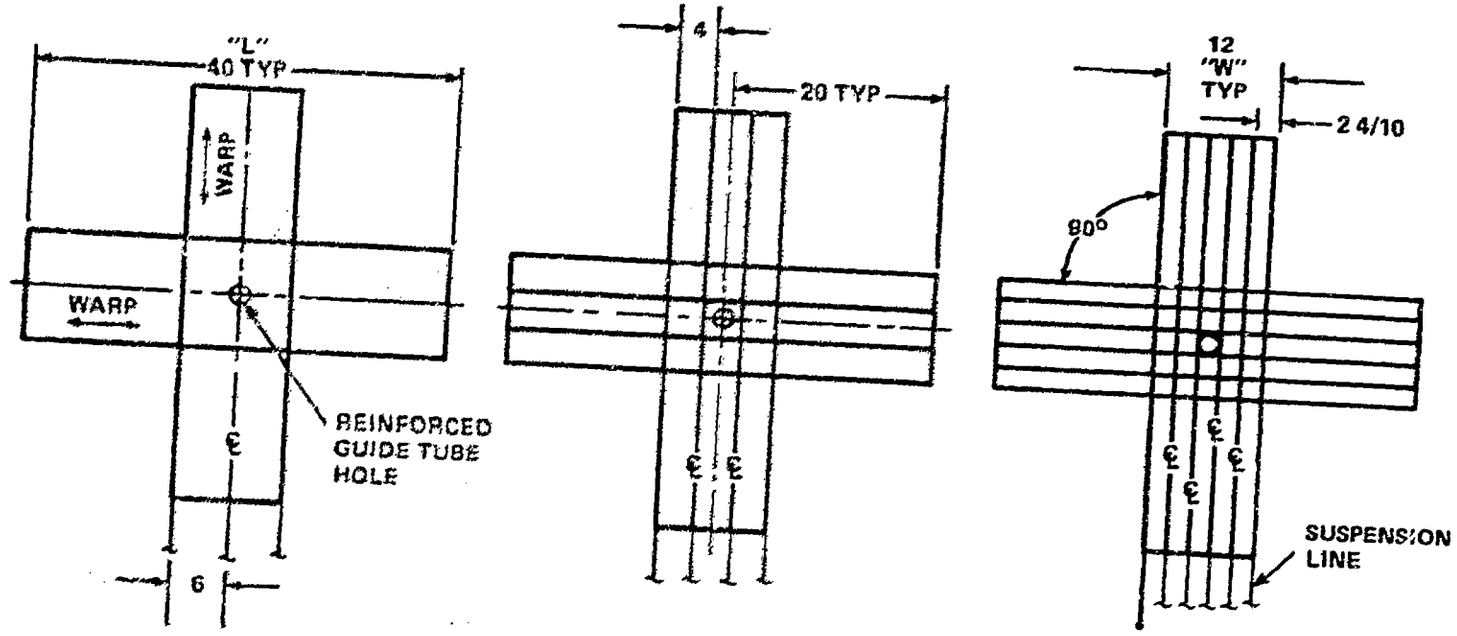


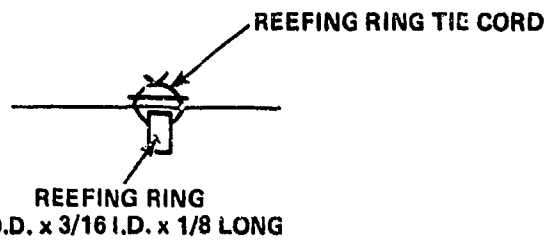
FIGURE 1 MODEL PARACHUTE CONFIGURATIONS—CONSTRUCTION DETAILS ARE SHOWN IN FIGURE 2

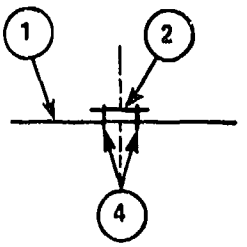
TABLE 1 MATERIALS USED IN MODEL PARACHUTE CONSTRUCTION

ITEM	MATERIAL	PARACHUTE		
1	CLOTH	MIL-C-7020, TYPE 1 AIR PERMEABILITY 98 CFM/FT^2 @ 1/2 INCH WATER PRESSURE DIFFERENTIAL	AIR PERMEABILITY 225 CFM/FT^2 @ 1/2 INCH WATER PRESSURE DIFFERENTIAL	AIR PERMEABILITY 351 CFM/FT^2 FT^3/FT^2/MIN @ 1/2 INCH WATER PRESSURE DIFFERENTIAL
2	TAPE	MIL-T-5038, TAPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 1/2 INCH WIDE
3	SUSPENSION[1] LINE	MIL-C-17183	MIL-C-17183	MIL-C-17183
4	STITCHES[2]	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, 2 ROWS ON 1/4 INCH NEEDLE GAUGE		
5	STITCHES	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, SINGLE ROW		

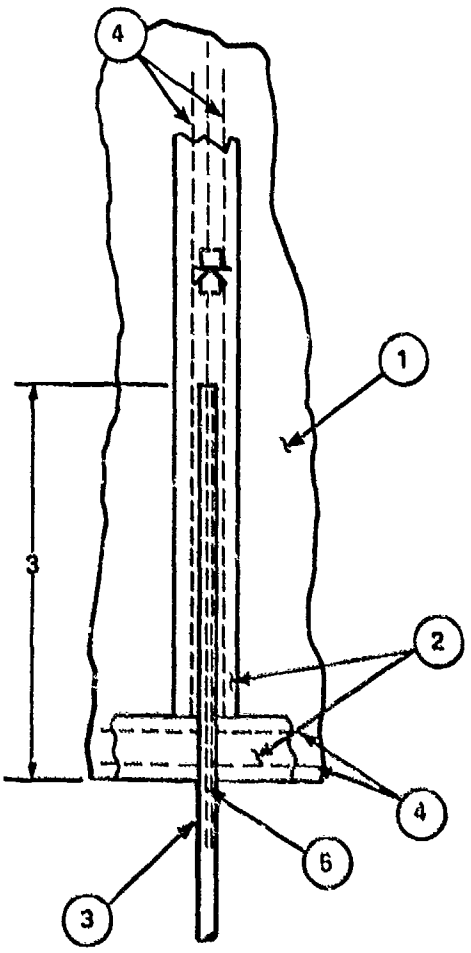
[1] 12 SUSPENSION LINE CANOPIES USE, TYPE VI, 500 LB TENSILE STRENGTH
16 SUSPENSION LINE CANOPIES USE, TYPE IV, 300 LB TENSILE STRENGTH
24 SUSPENSION LINE CANOPIES USE, TYPE III, 200 LB TENSILE STRENGTH

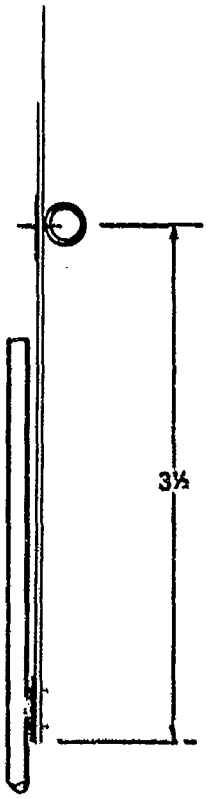
[2] ALL THREAD, V-T-295. TYPE I OR II, CLASS A, SIZE B





TYPICAL TAPE – CANOPY CROSS SECTION





SKIRT HEM – SUSPENSION LINE ASS'Y

FIGURE 2 MODEL PARACHUTE CONSTRUCTION DETAILS
SEE TABLE 1 FOR MATERIALS IDENTIFICATION

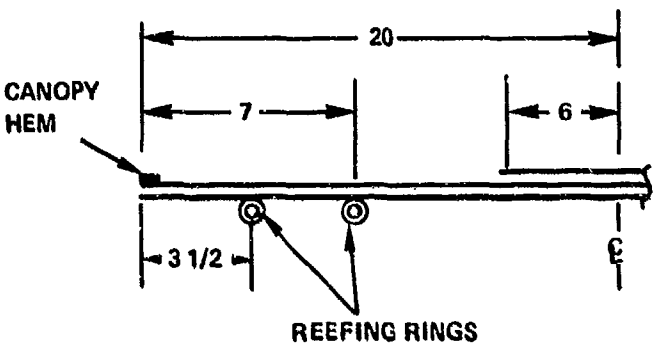


FIGURE 3 LOCATION OF REEFING RINGS ON CANOPY RADIAL TAPE

The air permeability of each canopy cloth was measured by means of a Frazier Fabric Permeability Machine (No. 79A). Ten determinations of the rate of air flow were made at 1/2 inch water pressure differential across the cloth. The average value and statistical one sigma variation are listed below.

CFM/FT^2

Nominal	1 σ variation
98.3	2.7
225.0	7.3
351.2	1.8

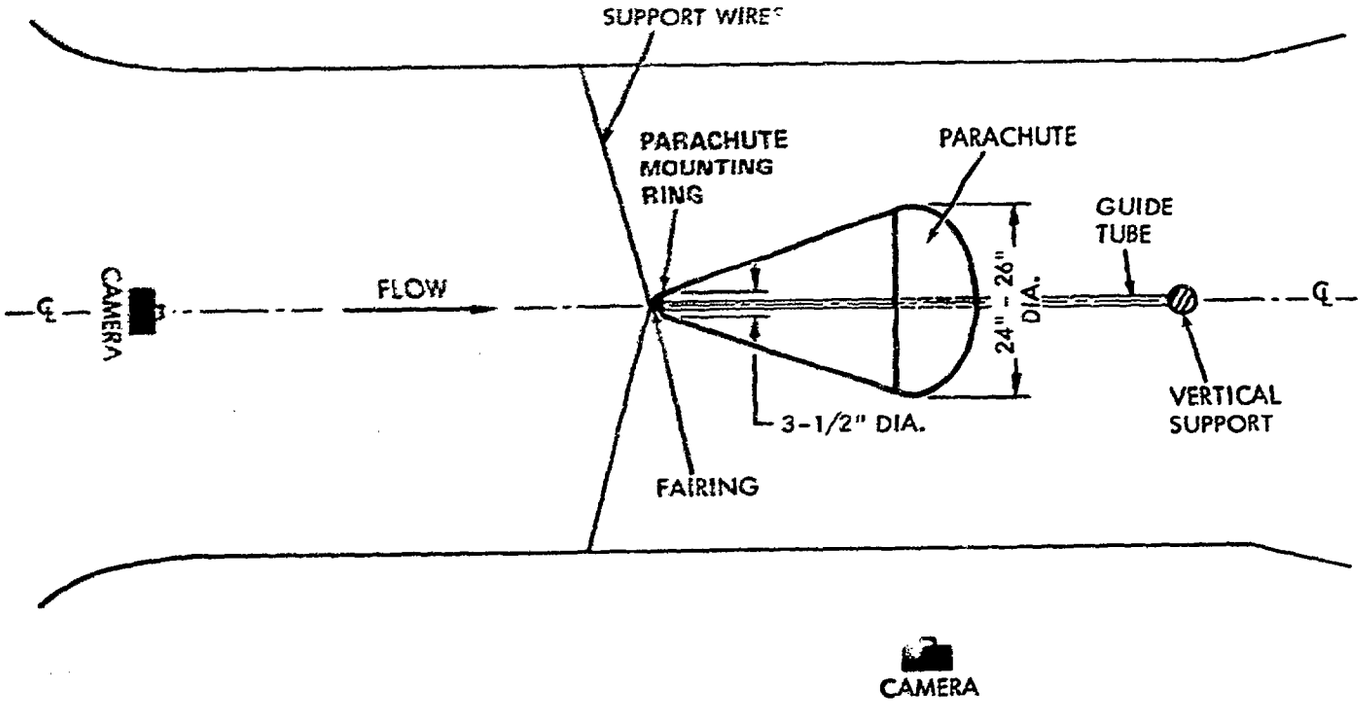
INSTRUMENTATION. The Wind Tunnel support system, Figure 4 was designed to position the model parachutes. Parachute oscillations were controlled by a support rod along the wind-tunnel centerline which passed through the center of the canopy. Guy wires were used to stabilize the support rod and maintain a relatively uncluttered test section. In all tests the parachute suspension lines were attached to the parachute mounting ring which was machined so that it was connected to the support rod by four beams. Strain gages were secured to two of these beams in such a manner that they could be used to measure the total drag load. See Figures 5, 6, and 7. The strain gage bridge is composed of four active gages. Bending of the beams by the parachute force causes gages 1 and 2 to be in compression, and gages 3 and 4 to be in tension.

Prior to installation of the mounting ring the sensitivity and linearity of the gages were verified by loading the suspended assembly with weights. The entire system was recalibrated after installation in the wind tunnel. The strain gage bridges were connected to an amplifier which was in turn connected to a Hewlett Packard (HP) computer through an analog to digital converter. Once the amplifier gain was adjusted it was not changed throughout the test, See Figure 8. The bridges were very stable with essentially no zero shift throughout the test program.

During calibration the repeatability of gage number 2 was somewhat better than gage number 1. Therefore, bridge number 2 was used as the true drag reading and gage number 1 was a backup. The entire test utilized gage number 2.

The computer is capable of detecting $\pm$ 0.005 volts, which from the calibration is approximately $\pm$ 0.25 lbs. During test runs the computer recorded test data at 500 samples per second for 1.54 seconds and calculated the average value and the standard variation. Prior to each test run a wind off zero was recorded which was then subtracted from subsequent wind on data. The voltages recorded during test runs were converted to pounds of drag in the computer, recorded on magnetic tape, and visually displayed for each data point. The drag data repeatability was within 0.5% for most of the parachutes tested.

Reefing line forces were measured by special load cells designed for this test. Five gage bodies were machined in the configuration of Figure 9. Some of these were gaged with two active gages and some with four. The cell used for the majority of the reefing line tests had four active gages. These cells were all calibrated to check the sensitivity and linearity outside of the tunnel, prior to testing, in the same manner as the total force bridges. Then they were calibrated through the system prior to being installed in the parachute. The



WIND TUNNEL CROSS SECTION DIMENSIONS 7 FT x 11 FT

FIGURE 4 PLAN VIEW OF WIND TUNNEL SUPPORT AND PHOTOGRAPHIC SYSTEMS

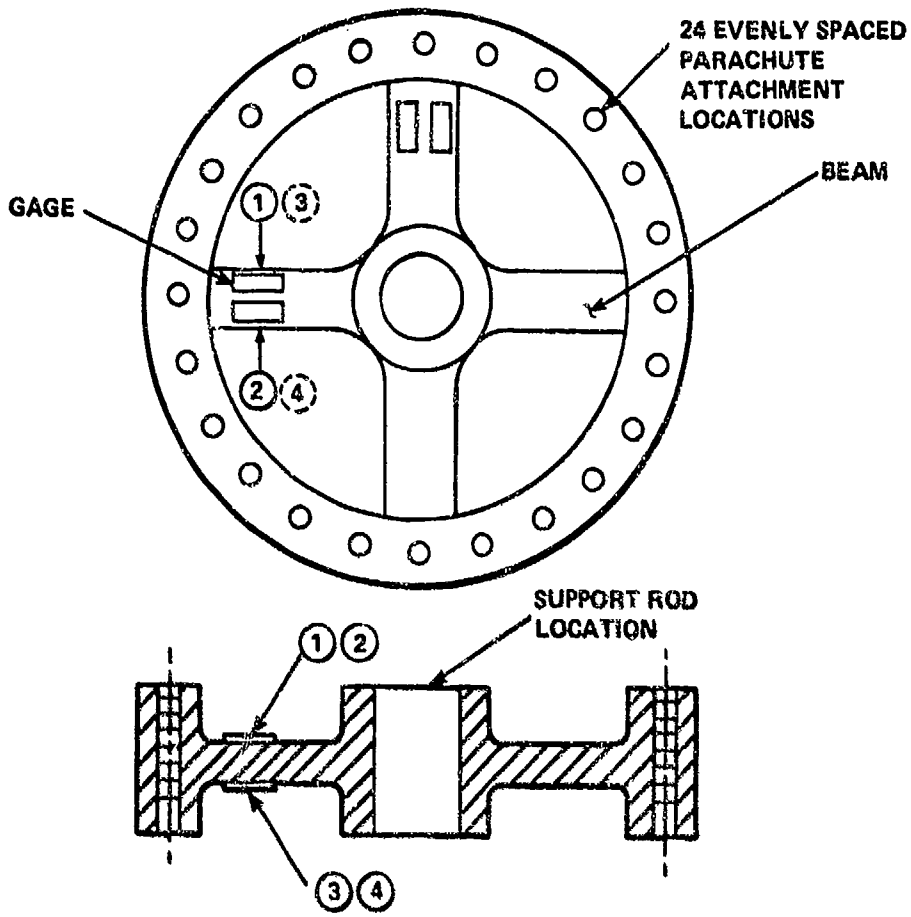


FIGURE 5 PARACHUTE MOUNTING RING FOR TOTAL DRAG LOAD MEASUREMENT

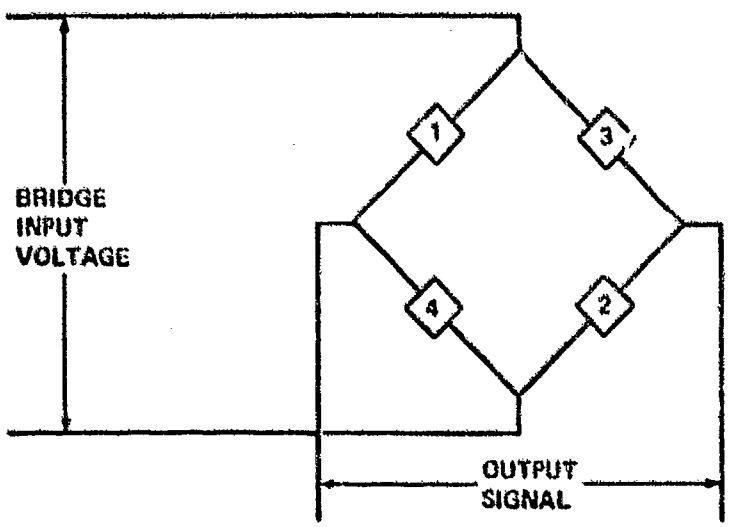


FIGURE 6 METHOD OF CONNECTING STRAIN GAGES ON RING BEAM

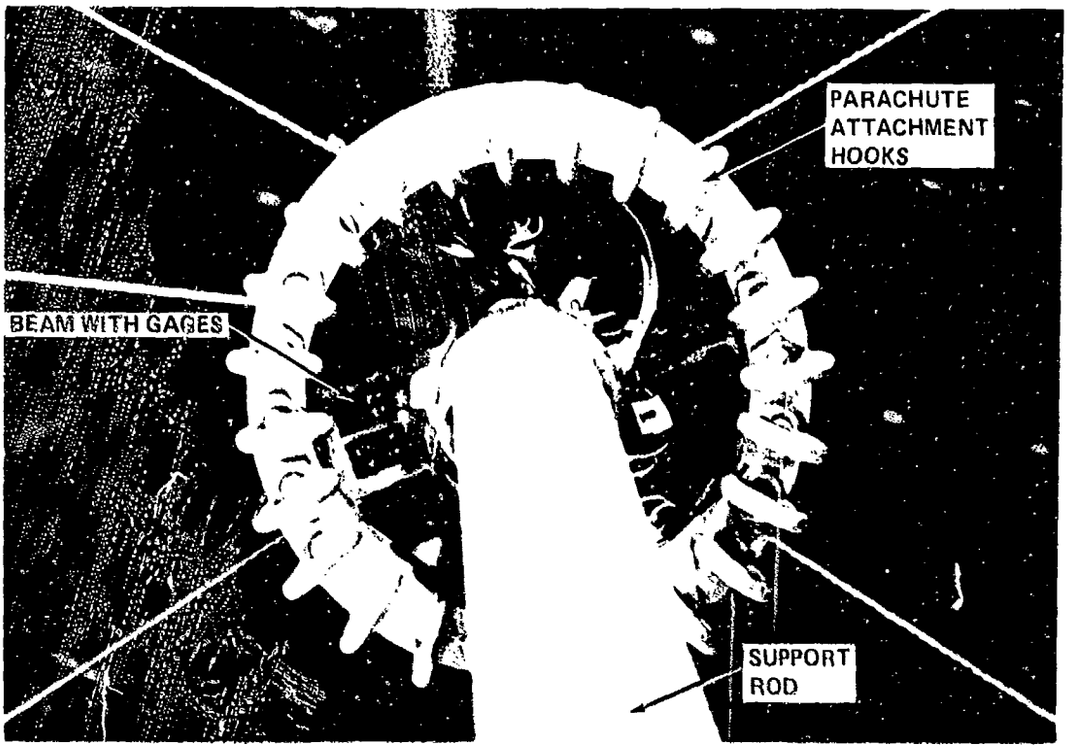


FIGURE 7 PARACHUTE MOUNTING RING

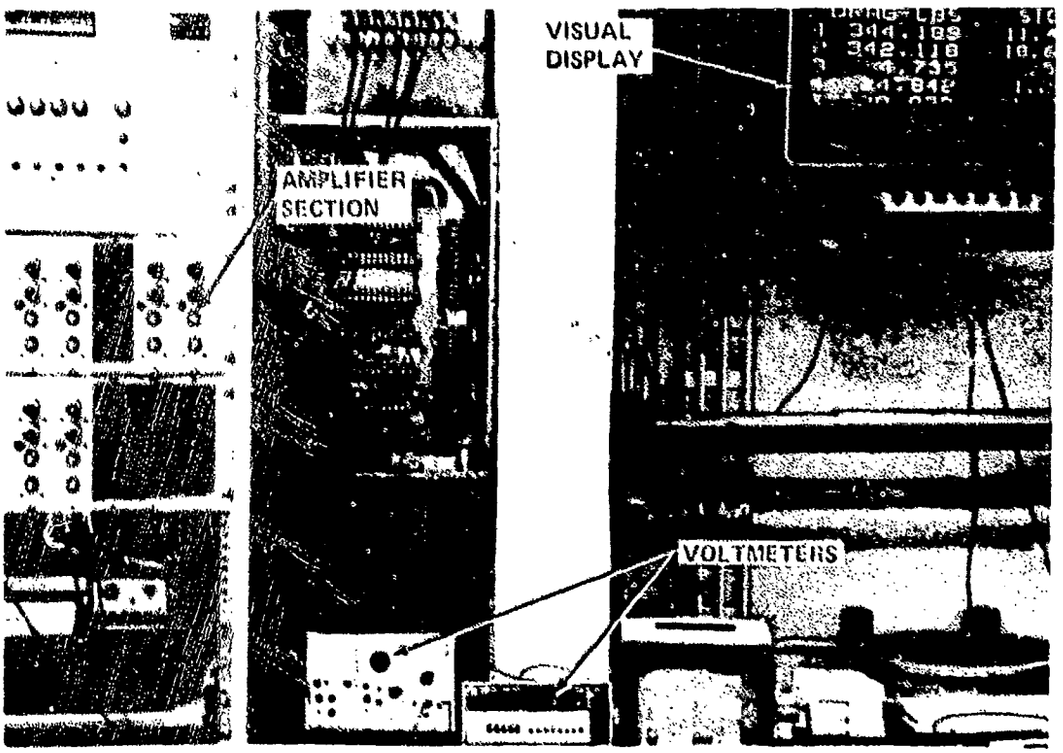


FIGURE 8 PARACHUTE FORCE MEASUREMENT EQUIPMENT

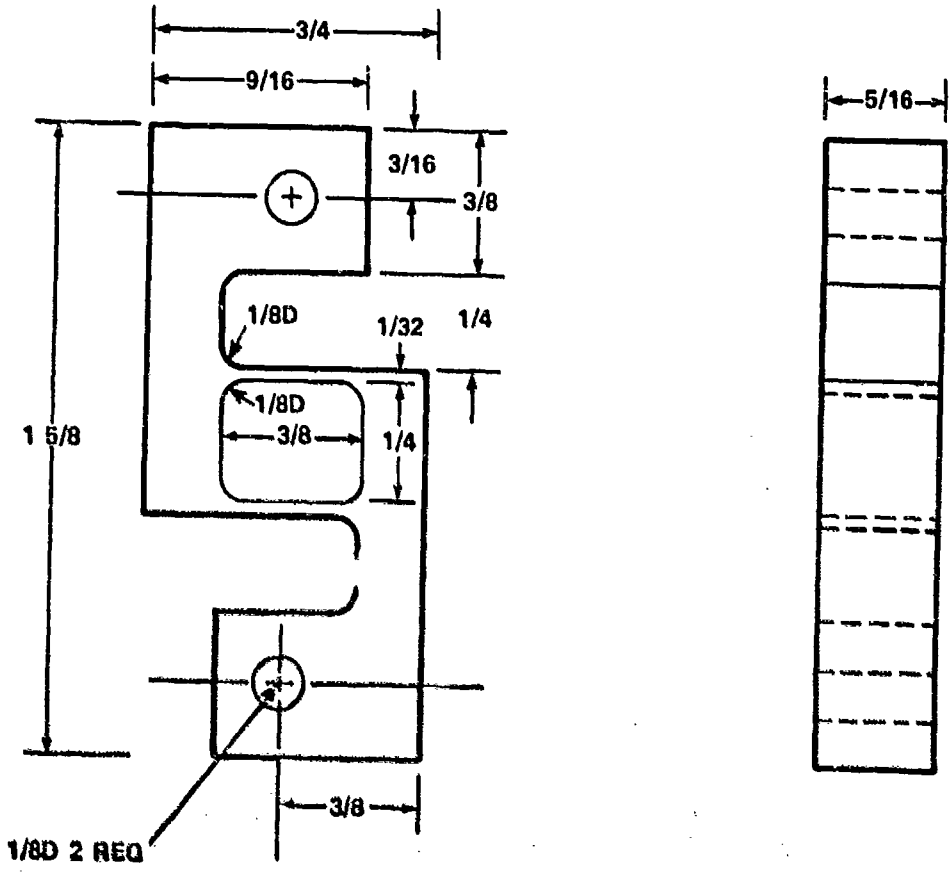


FIGURE 9 GAGE BODY, 7075 ALUMINUM

sensitivity of these cells was such that the minimum resolution was approximately ± .02 pounds. No reefing point runs were repeated in order to determine the repeatibility of the force reading so there is nothing definite that can be said about this point. If the confidence level is assumed to be ten times the minimum resolution, this results in a value of ± 0.2 pounds. Since the data were averaged over 1.54 seconds, it seems reasonable to assume the data is accurate within this range.

A 1/32 inch diameter flexible steel cable was used for the reefing line. The load cell was installed directly in the reefing line so that the force in the reefing line put the cell in tension. The electrical leads from the cell were taped to the reefing line where the cell was mounted to minimize the flexing of the instrumentation wiring at this point. See Figures 10 and 11. The leads were then attached to the support rod with sufficient length to allow the cable to flex freely between the reefing line and the support rod.

Two 35mm still cameras were used to record canopy shapes. One camera was installed upstream in the wind tunnel to record canopy mouth shapes (not published) and the other camera was located outside the wind tunnel to record the canopy profiles.

TEST PROCEDURE. Each parachute was subjected to two series of tests to determine (1) the fully inflated aerodynamic drag at various wind tunnel velocities, and (2) the percent reefed as a function of reefing line length. Flexible steel cable 1/32 inch in diameter was used as a reefing line to minimize elongation under sustained use, and because a known length could be quickly, easily, and repeatably removed. Nico-press fittings were used to join the ends of the reefing line.

All parachutes were mounted on the support rod and the suspension lines were connected in sequence to the mounting ring. Aerodynamic drag of fully open parachutes was recorded at wind tunnel velocities of 50, 60, 70, 80, 100, 150, 200, 250, and 293 feet per second. The reefing line was then installed with the calibrated reefing line force gage and the reefed drag and reefing line forces were measured at a velocity of 293 feet per second for five reefing line lengths.

Special reefing tests were conducted on the first parachute. The reefed drag was measured with the reefing line installed in the forward set of reefing rings, (0.0875L) and repeated with the reefing line installed in the aft set of reefing rings, (0.175L). Reefed parachute performance, Figure 12, was similar for either reefing line location. Figure 13 illustrates the inflated reefed canopy shapes. It was decided to conduct the reefing tests using the forward set of reefing rings on the basis that the larger mouth area would likely cause the parachute to inflate more rapidly when disreefed.

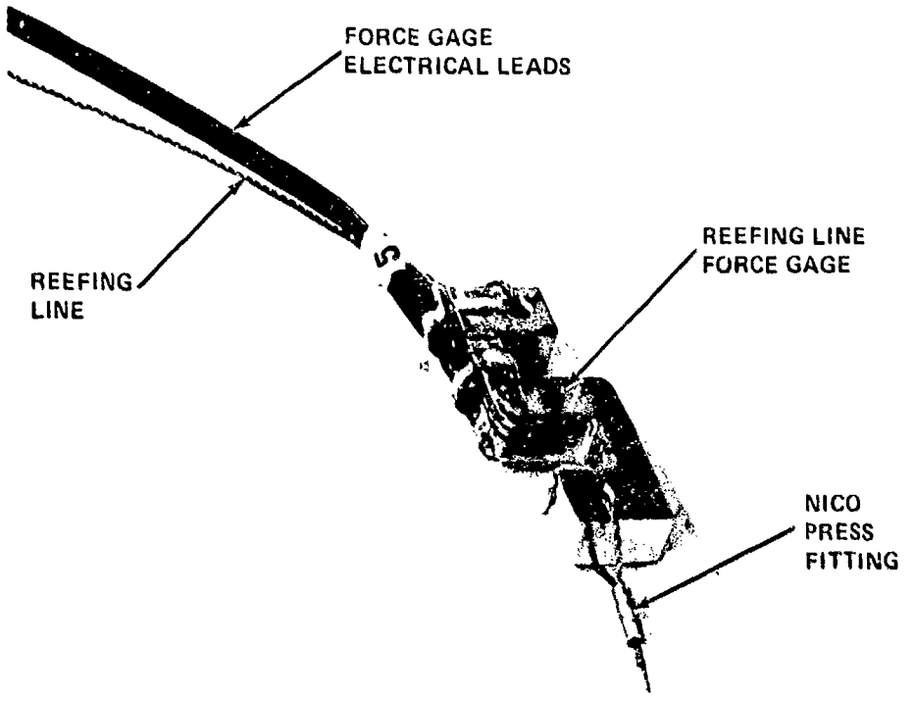


FIGURE 10 METHOD OF ATTACHING THE REEFING LINE TO THE FORCE GAGE

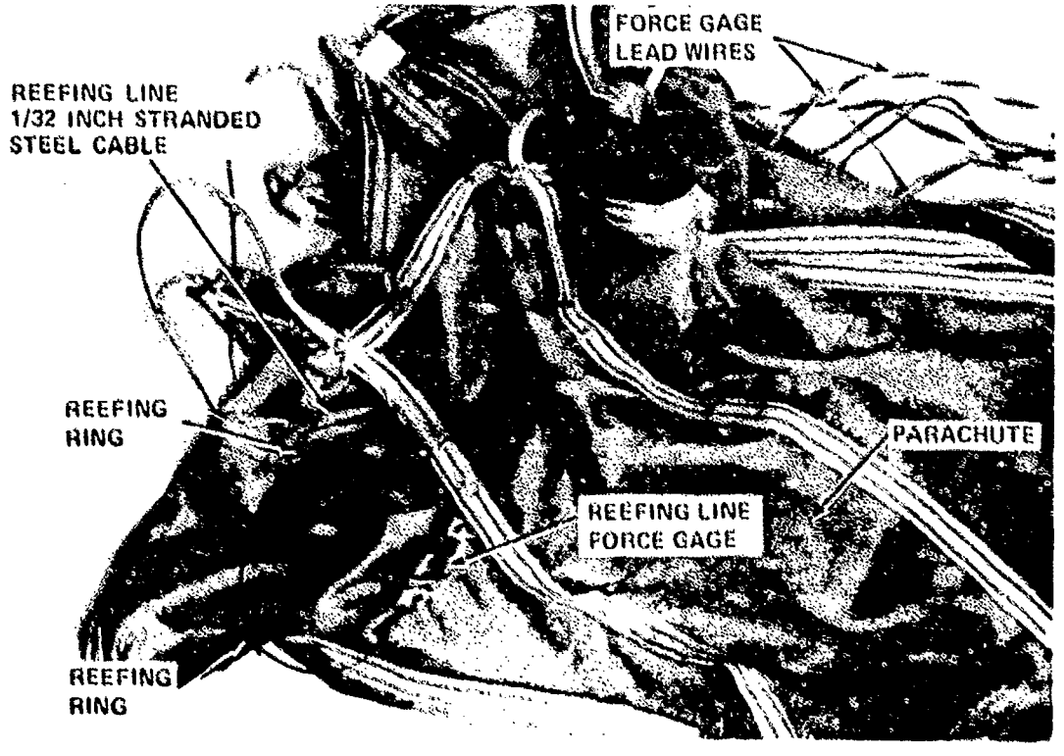


FIGURE 11 TYPICAL REEFING LINE AND FORCE GAGE INSTALLED IN PARACHUTE

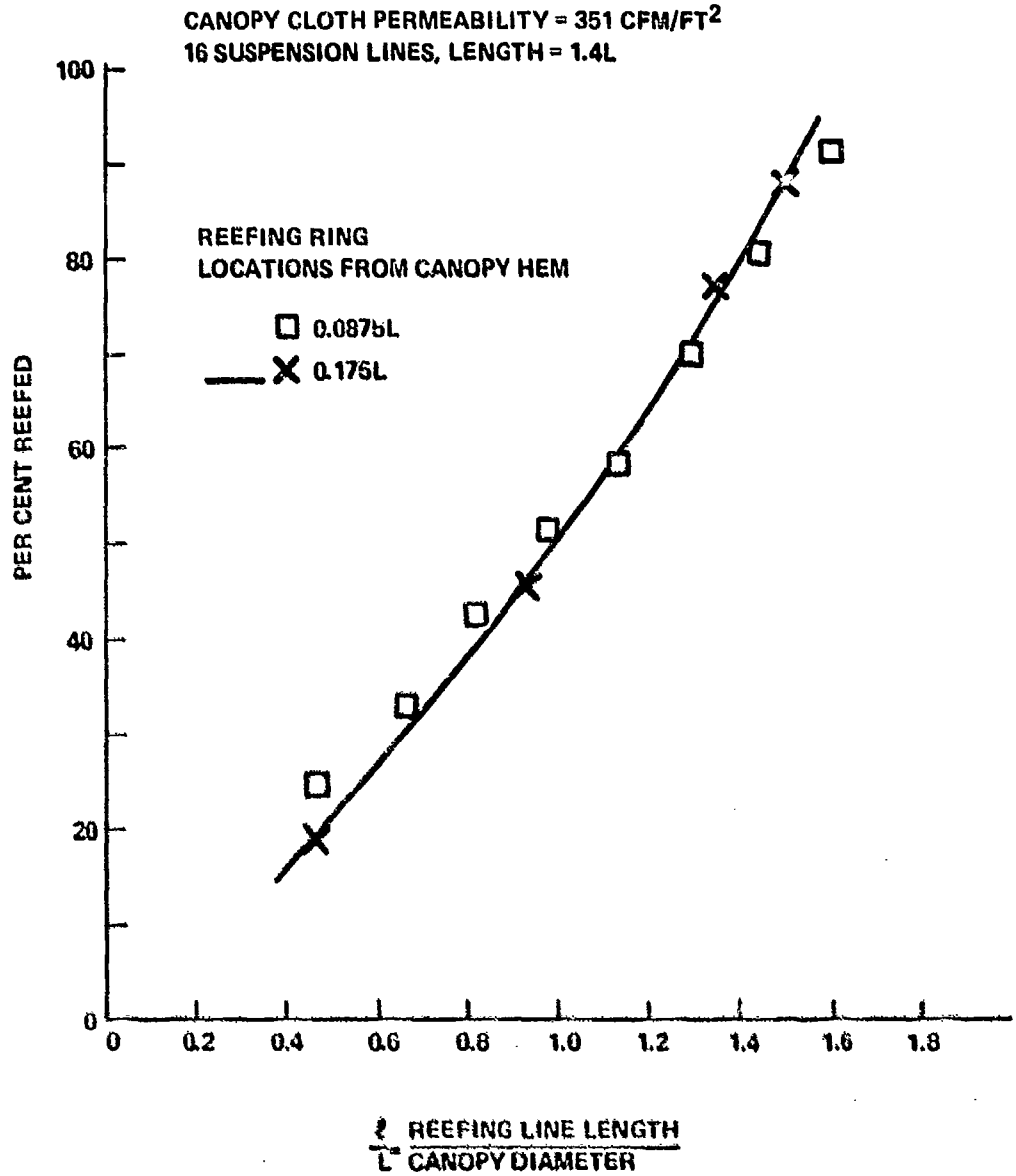
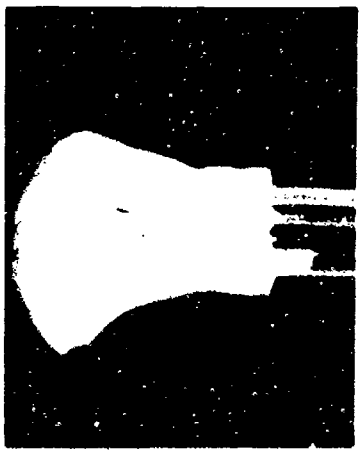


FIGURE 12 COMPARISON OF REEFING CHARACTERISTICS FOR REEFING LINES LOCATED AT THE 0.0875L AND 0.175 POSITIONS

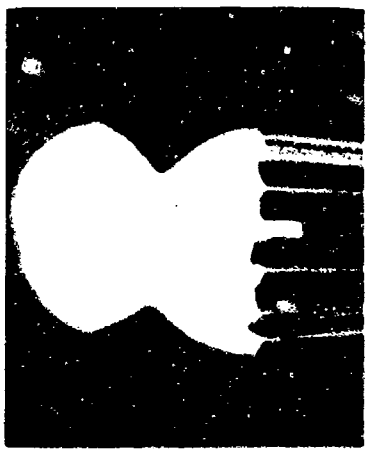
REEFING LINE LOCATION AT 0.0875 L



$\frac{\ell}{L} = 0.469$

18.9% REEFED

REEFING LINE LOCATION AT 0.175 L



$\frac{\ell}{L} = 0.475$

24.8% REEFED

FIGURE 13 EFFECT OF REEFING LINE LOCATION ON THE INFLATED REEFED CANOPY SHAPE

DATA REDUCTION. The test data were reduced to coefficient form by use of the following formulae:

$$q = 1/2 \rho V^2 \quad , \quad lb/ft^2$$

$$S_o = 2LW - W^2 \quad , \quad ft^2$$

$$C_D = \frac{D}{qS_o}$$

$$\% \text{ reefed} = \frac{\text{Parachute drag in reefed condition at velocity V}}{\text{Drag of fully opened parachute at same velocity}} \times 100$$

$$\% \text{ reefing line load} = \frac{\text{Force in reefing line at velocity V}}{\text{Drag of fully opened parachute at same velocity}} \times 100$$

The reference area of all parachutes used in this test is 5.667 ft^2.

RESULTS

Test results are presented in tabular and graphical format together with selected photographs of fully inflated and reefed canopy profiles. Some generalized observations from the test data are presented. The user should refer to the test data in order to assure himself that the generalized results are applicable to the particular configuration under consideration.

DRAG COEFFICIENTS. The parachute total drag force was measured by the gages on the parachute mounting ring. The same total drag gages were used throughout the entire test program and had negligible zero shift. The statistical average drag force and the one sigma drag force variation were reduced from data collected at the rate of 500 samples per second for 1.54 seconds (770 data samples). The drag coefficient data is presented in Tables 2, 3, and 4 and, graphical drag coefficient representation is illustrated in Figures 14, 15, and 16. Generally the drag coefficients tend to increase as: a) cloth permeability decreases, b) suspension line lengths are increased, c) the test velocity is reduced below 60 fps. For some unknown reason the data taken at 70 fps is not generally consistent with other data of the same configuration.

The maximum (0.55) and minimum (0.000) one sigma drag coefficient values occur at the lowest dynamic pressures. The average one sigma value for the entire test is 0.016.

Example: From Table 2 the drag coefficient for a 12 suspension line parachute with line lengths of 1.0L and a canopy cloth permeability of 98 CFM/FT^2 at 250 fps is:

$$C_D = C_D \pm 1\sigma$$

$$C_D = 0.645 \pm 0.014$$

Photographs of a few typical fully inflated parachute profiles at various velocities are presented in Figures 17, 18, and 19. At wind tunnel velocities of 50 fps the W/L=0.3 parachute canopies are more fully inflated than geometrically similar W/L=0.264 parachutes of reference 1 as evidenced by the absence of wrinkles in the canopy cloth.

CANOPY REEFING. A 1/32 inch flexible steel reefing line of known length was installed in the parachute at the reefing ring set located at 0.0875 L. The steady state reefed drag force was measured at a velocity of 293 fps for each of the five reefing line lengths. The reefing line length was normalized to the canopy diameter, and the percent reefed determined by ratioing the reefed drag force to the fully inflated drag force at the same velocity. Table 5 lists the

TABLE 2 DRAG COEFFICIENT TEST DATA CLOTH PERMEABILITY = 98 CFM/FT^2

VELOCITY V fps	DYNAMIC PRESSURE q psf	DRAG COEFFICIENT								
		12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
		SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
		1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
50.0	2.97	0.707	0.695	0.674	0.671	0.710	0.767	0.693	0.775	0.746
60.0	4.28	0.727	0.692	0.653	0.655	0.710	0.765	0.672	0.743	0.723
70.0	5.83	0.723	0.713	0.682	0.654	0.737	0.803	0.684	0.778	0.765
80.0	7.61	0.690	0.684	0.675	0.628	0.708	0.774	0.659	0.725	0.741
100.0	11.89	0.672	0.679	0.678	0.624	0.710	0.773	0.657	0.738	0.744
150.0	26.75	0.661	0.676	0.681	0.623	0.712	0.756	0.665	0.748	0.753
200.0	47.56	0.654	0.675	0.689	0.626	0.723	0.763	0.669	0.747	0.758
250.0	74.31	0.645	0.677	0.680	0.626	0.731	0.761	0.666	0.754	0.760
293.3	102.28	0.649	0.683	0.683	0.630	0.740	0.734	0.673	—	0.763
1 SIGMA DRAG COEFFICIENT VARIATION										
50.0	2.97	0.000	0.027	0.000	0.030	0.028	0.000	0.028	0.030	0.027
60.0	4.28	0.019	0.055	0.031	0.026	0.026	0.022	0.021	0.024	0.023
70.0	5.83	0.020	0.022	0.016	0.021	0.020	0.022	0.019	0.023	0.021
80.0	7.61	0.017	0.017	0.019	0.015	0.016	0.022	0.022	0.023	0.021
100.0	11.89	0.015	0.017	0.014	0.014	0.018	0.019	0.018	0.022	0.021
150.0	26.75	0.015	0.016	0.021	0.014	0.017	0.018	0.016	0.019	0.019
200.0	47.56	0.014	0.015	0.015	0.015	0.016	0.018	0.018	0.022	0.020
250.0	74.21	0.014	0.015	0.015	0.014	0.016	0.018	0.017	0.022	0.022
293.3	102.28	0.016	0.015	0.014	0.016	0.017	0.017	0.017	—	0.020

TABLE 3 DRAG COEFFICIENT TEST DATA CLOTH PERMEABILITY = 225 CFM/FT^2

VELOCITY V fps	DYNAMIC PRESSURE q psf	DRAG COEFFICIENT								
		12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
		SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
		1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
50.0	2.97	0.753	0.667	0.710	0.613	0.729	0.674	—	0.726	0.735
60.0	4.28	0.657	0.646	0.684	0.597	0.688	0.676	0.605	0.730	0.710
70.0	5.83	0.650	0.678	0.682	0.606	0.716	0.671	0.629	0.712	0.756
80.0	7.61	0.618	0.654	0.662	0.581	0.695	0.668	0.601	0.710	0.714
100.0	11.89	0.591	0.636	0.650	0.568	0.687	0.661	0.600	0.696	0.714
150.0	26.75	0.571	0.633	0.640	0.549	0.676	0.657	0.611	0.698	0.714
200.0	47.56	0.562	0.630	0.639	0.553	0.674	0.659	0.605	0.693	0.729
250.0	74.31	0.555	0.628	0.634	0.560	0.678	0.658	0.610	0.697	0.720
293.3	102.28	0.558	0.633	0.635	0.566	0.681	0.659	0.615	0.700	0.726
1 SIGMA DRAG COEFFICIENT VARIATION										
50.0	2.97	0.000	0.039	0.000	0.000	0.000	0.000	—	0.000	0.000
60.0	4.28	0.019	0.020	0.020	0.000	0.000	0.020	0.019	0.021	0.019
70.0	5.83	0.017	0.019	0.014	0.015	0.016	0.017	0.018	0.017	0.020
80.0	7.61	0.015	0.015	0.013	0.016	0.016	0.017	0.015	0.016	0.017
100.0	11.89	0.018	0.015	0.014	0.012	0.015	0.016	0.018	0.013	0.015
150.0	26.75	0.013	0.012	0.013	0.011	0.014	0.017	0.015	0.015	0.016
200.0	47.56	0.012	0.014	0.013	0.011	0.014	0.017	0.016	0.014	0.015
250.0	74.31	0.013	0.014	0.013	0.014	0.015	0.017	0.015	0.015	0.017
293.3	102.28	0.013	0.014	0.015	0.014	0.015	0.018	0.016	0.015	0.016

TABLE 4 DRAG COEFFICIENT TEST DATA CLOTH PERMEABILITY = 351 CFM/FT^2

VELOCITY V fps	DYNAMIC PRESSURE q psf	DRAG COEFFICIENT								
		12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
		SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
		1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
50.0	2.97	0.549	0.624	0.750	0.489	0.484	0.644	0.574	0.765	0.644
60.0	4.28	0.536	0.621	0.696	0.495	0.532	0.641	0.551	0.696	0.631
70.0	5.83	0.541	0.635	0.705	0.501	0.533	0.642	0.565	0.686	0.673
80.0	7.61	0.520	0.618	0.662	0.510	0.546	0.633	0.539	0.656	0.657
100.0	11.89	0.515	0.601	0.642	0.497	0.548	0.612	0.532	0.659	0.665
150.0	26.75	0.512	0.606	0.628	0.490	0.558	0.607	0.527	0.651	0.669
200.0	47.56	0.522	0.604	0.621	0.501	0.569	0.619	0.527	0.655	0.673
250.0	74.31	0.526	0.600	0.616	0.510	0.580	0.622	0.538	0.655	0.680
293.3	102.28	0.530	0.596	0.618	0.513	0.587	0.625	0.546	0.661	0.677
1 SIGMA DRAG COEFFICIENT VARIATION										
50.0	2.97	0.038	0.000	0.000	0.038	–	0.000	0.000	0.000	0.000
60.0	4.28	0.020	0.000	0.000	0.000	–	0.020	0.000	0.019	0.000
70.0	5.83	0.017	0.018	0.014	0.015	–	0.021	0.017	0.016	0.015
80.0	7.61	0.015	0.014	0.013	0.012	–	0.019	0.016	0.014	0.014
100.0	11.89	0.013	0.012	0.013	0.013	–	0.015	0.015	0.013	0.015
150.0	26.75	0.012	0.013	0.011	0.011	–	0.016	0.018	0.014	0.013
200.0	47.56	0.012	0.013	0.013	0.013	–	0.018	0.013	0.014	0.014
250.0	74.31	0.013	0.014	0.014	0.013	–	0.020	0.014	0.016	0.013
293.3	102.28	0.014	0.014	0.014	0.013	–	0.021	0.015	0.017	0.014

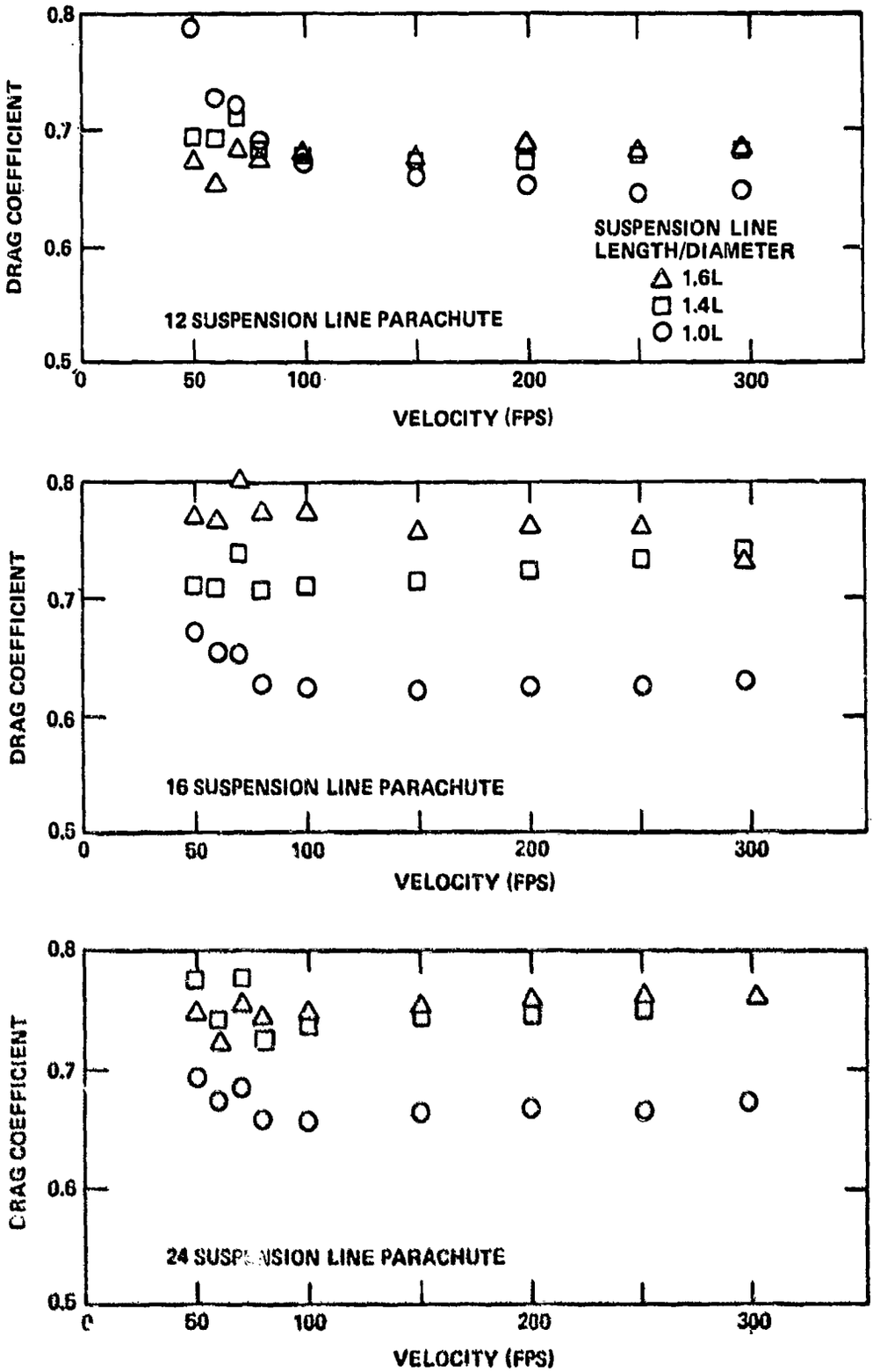


FIGURE 14 DRAG COEFFICIENT TEST DATA CANOPY CLOTH, MIL-C-7020, TYPE I PERMEABILITY = 98 CFM/FT^2

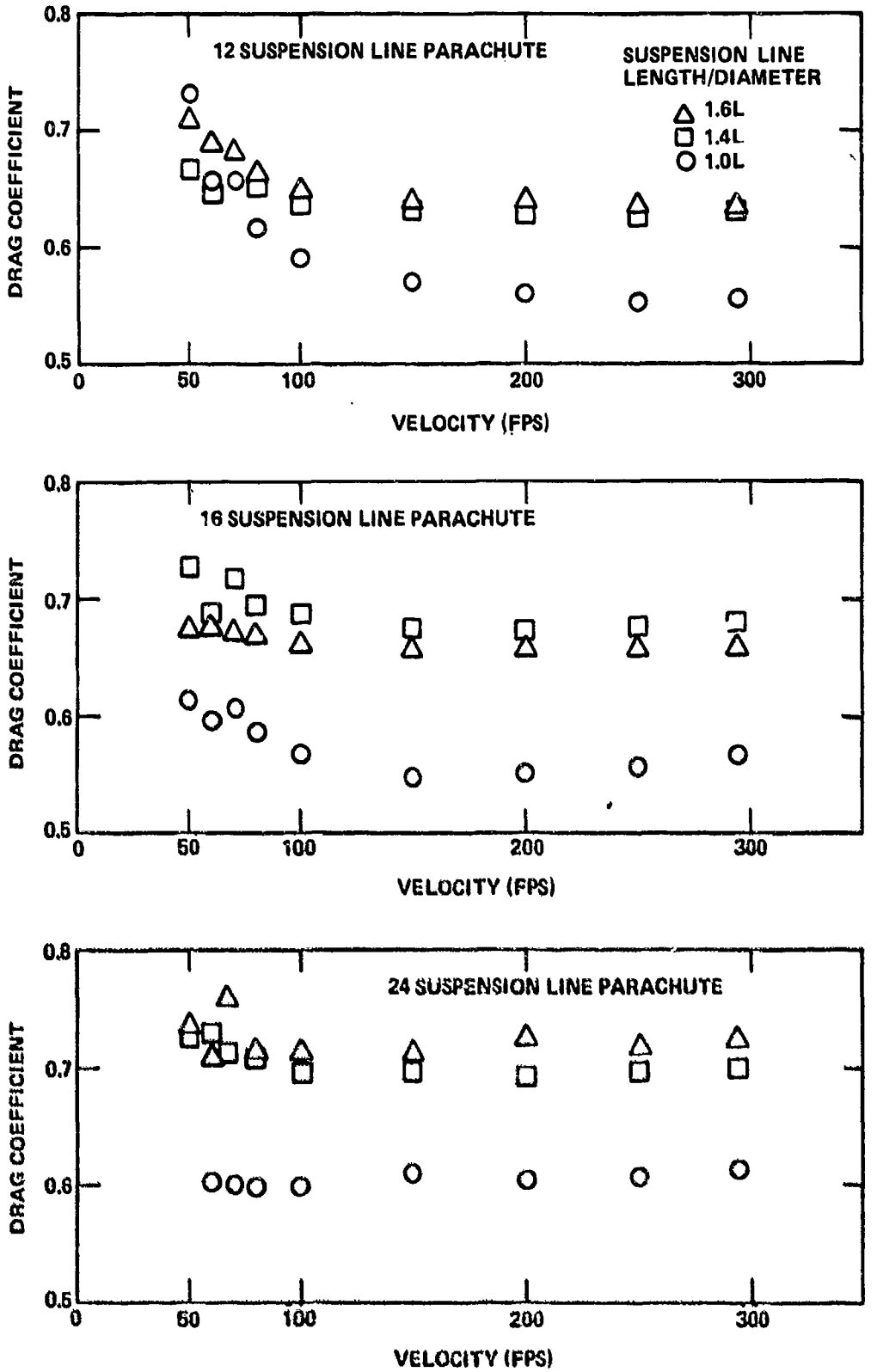


FIGURE 15 DRAG COEFFICIENT TEST DATA CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2

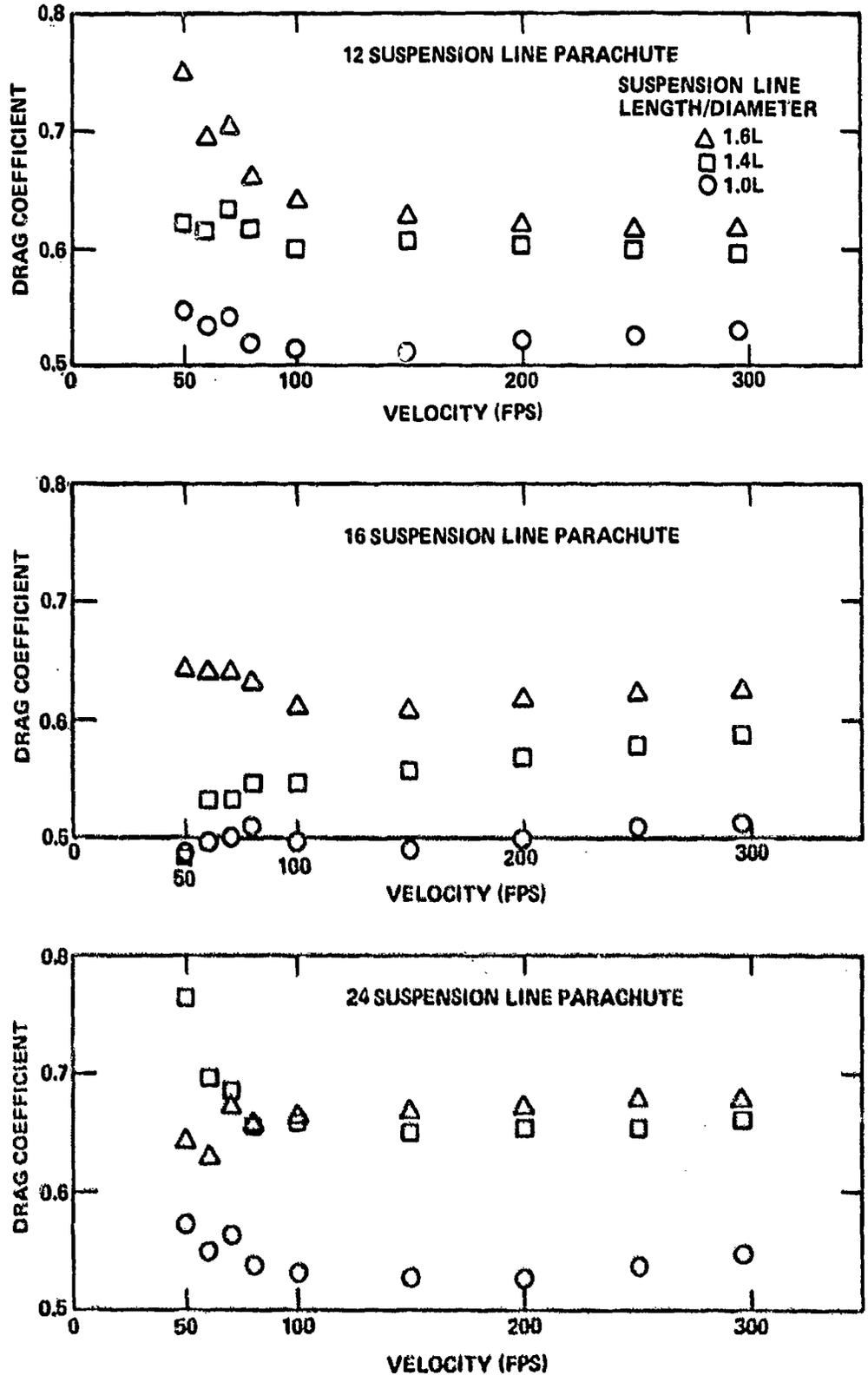
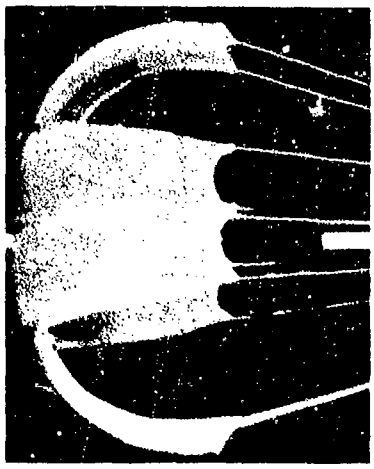
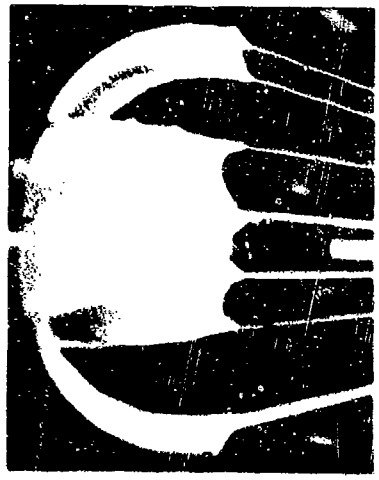


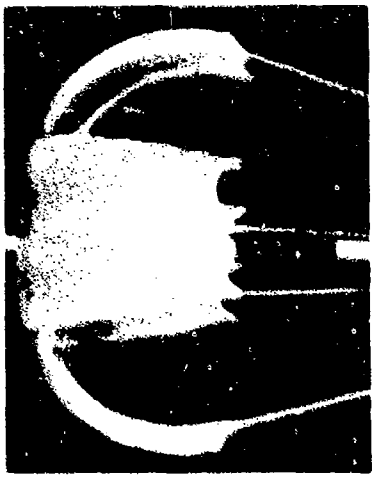
FIGURE 16 DRAG COEFFICIENT TEST DATA CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2



VELOCITY = 50 FPS

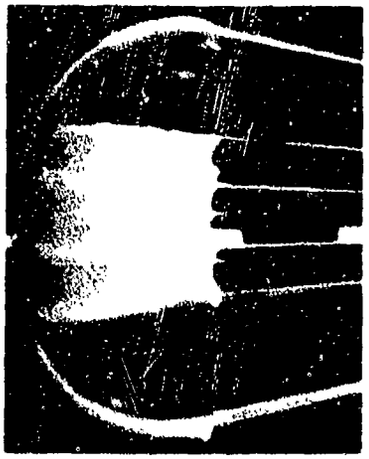
VELOCITY = 100 FPS





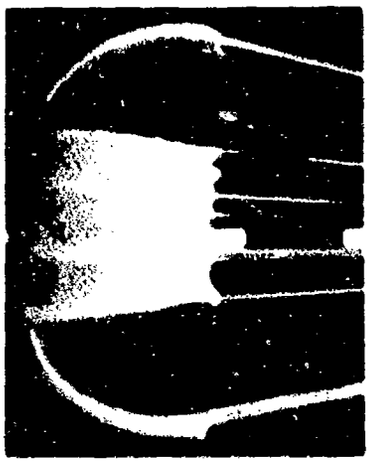
VELOCITY = 200 FPS

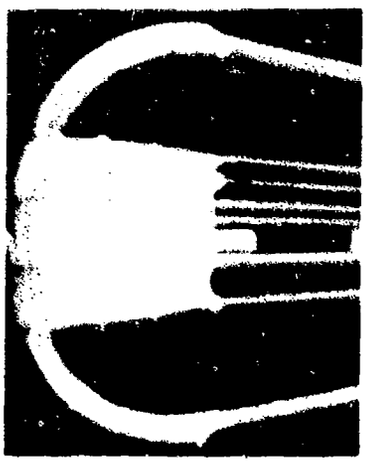
FIGURE 17 DRAG COEFFICIENT TEST; CLOTH PERMEABILITY = 98 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L



VELOCITY = 50 FPS

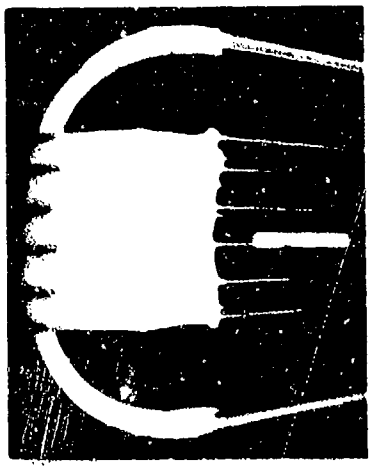
VELOCITY = 100 FPS





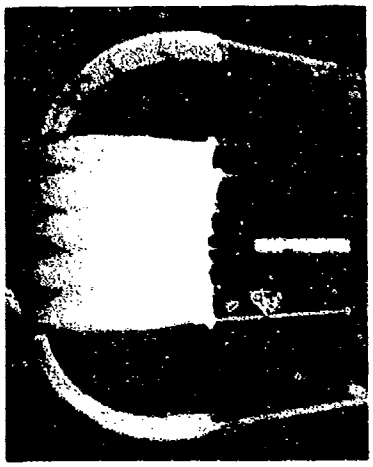
VELOCITY = 200 FPS

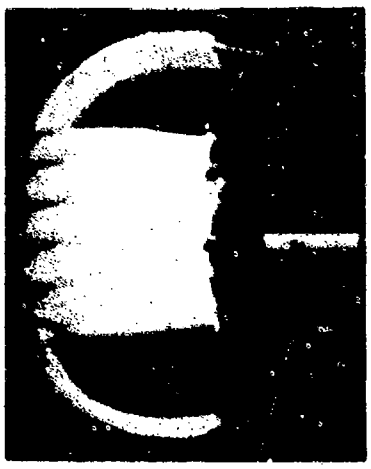
FIGURE 18 DRAG COEFFICIENT TEST; CLOTH PERMEABILITY = 225 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L



VELOCITY = 50 FPS

VELOCITY = 100 FPS





VELOCITY = 200 FPS

FIGURE 19 DRAG COEFFICIENT TEST; CLOTH PERMEABILITY = 351 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L

TABLE 5 REEFED CANOPY TEST DATA TEST VELOCITY = 293 FPS

REEFING LINE LENGTH / CANOPY DIAMETER $\frac{\ell}{L}$	PERCENT REEFED								
	12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
	SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
CANOPY CLOTH PERMEABILITY = 98 CFM/FT^2									
1.60	91.2	85.0	82.1	88.9	81.0	78.2	82.4	77.3	74.5
1.35	74.6	67.9	67.1	73.1	65.2	62.3	65.7	61.0	60.9
1.10	56.1	51.6	51.3	57.1	50.4	48.8	51.6	45.9	47.4
0.85	38.9	36.4	36.7	41.4	36.6	34.6	38.7	33.0	39.1
0.60	26.7	25.5	24.4	27.0	24.7	22.9	26.8	23.1	26.7
CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2									
1.60	96.3	89.8	86.2	95.4	84.3	83.7	88.1	80.9	96.4
1.35	79.5	73.6	69.7	77.4	67.0	66.5	70.2	64.9	80.6
1.10	62.2	57.3	47.2	58.0	50.4	49.7	52.9	48.9	62.7
0.85	45.1	40.9	33.9	40.4	35.6	37.9	38.2	35.6	48.1
0.60	27.6	26.1	20.6	26.0	24.1	30.6	24.9	22.8	36.2
CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2									
1.60	97.4	93.3	90.5	95.7	91.8	86.2	94.3	84.6	81.7
1.35	78.2	74.3	70.5	78.4	74.2	71.6	75.7	67.1	64.4
1.10	53.8	55.4	46.7	60.4	56.4	56.0	57.9	50.2	48.9
[illegible]	34.5	37.8	27.9	42.7	44.8	43.4	42.1	39.0	35.0
0.60	24.7	—	15.6	27.5	29.8	30.2	26.1	22.8	18.9

percent reefed as a function of normalized reefing line length (ℓ/L) and cloth permeability. Figures 20, 21, and 22 graphically illustrate the data. Reefed canopy shapes are shown in Figures 23 through 49.

The photographs in Figures 23 through 49 show that the canopy cloth in the area adjacent to the reefing line is pressurized rather than the desired uninflated conical zone. This condition indicates a rapid inflation at disreef. There does not appear to be any inflation time advantage in reefing a cross parachute at locations other than at the canopy hem.

REEFING LINE FORCES The forces in the reefing line were measured in the same manner as the total drag forces using the gages of Figure 10. Several gages were used in the various tests. Each gage was calibrated mounted in the wind tunnel through the data measuring system and had negligible zero shift during the tests. The force in the reefing line is presented, in Table 6 as a percent of the parachute fully inflated drag force for normalized reefing line lengths and cloth permeability. One sigma variations are presented in Table 7. Graphical representation of the data is shown in Figures 50, 51, and 52.

Example: From Table 6 for a 12 suspension line parachute with a line length of 1.0L, cloth permeability of 225CFM/FT^2 and ℓ/L=0.85. The reefing line force is 2.67 percent, and from Table 7 the one sigma variation for the same configuration is 0.19 percent.

Therefore $$\frac{\text{Reefing line force}}{\text{fully open drag}} \times 100 = 2.67 \pm 0.19$$

$$\text{Reefing line force} = \frac{2.67 \pm 0.19}{100} \times \text{fully open drag}$$

The following generalized observations of the reefing line force data are:

a. The maximum reefing line force occurs between $1.0 < \ell/L < 1.4$.

b. The maximum reefing line force decreases as cloth permeability increases.

c. The minimum reefing line force is associated with 1.0L suspension Line parachutes.

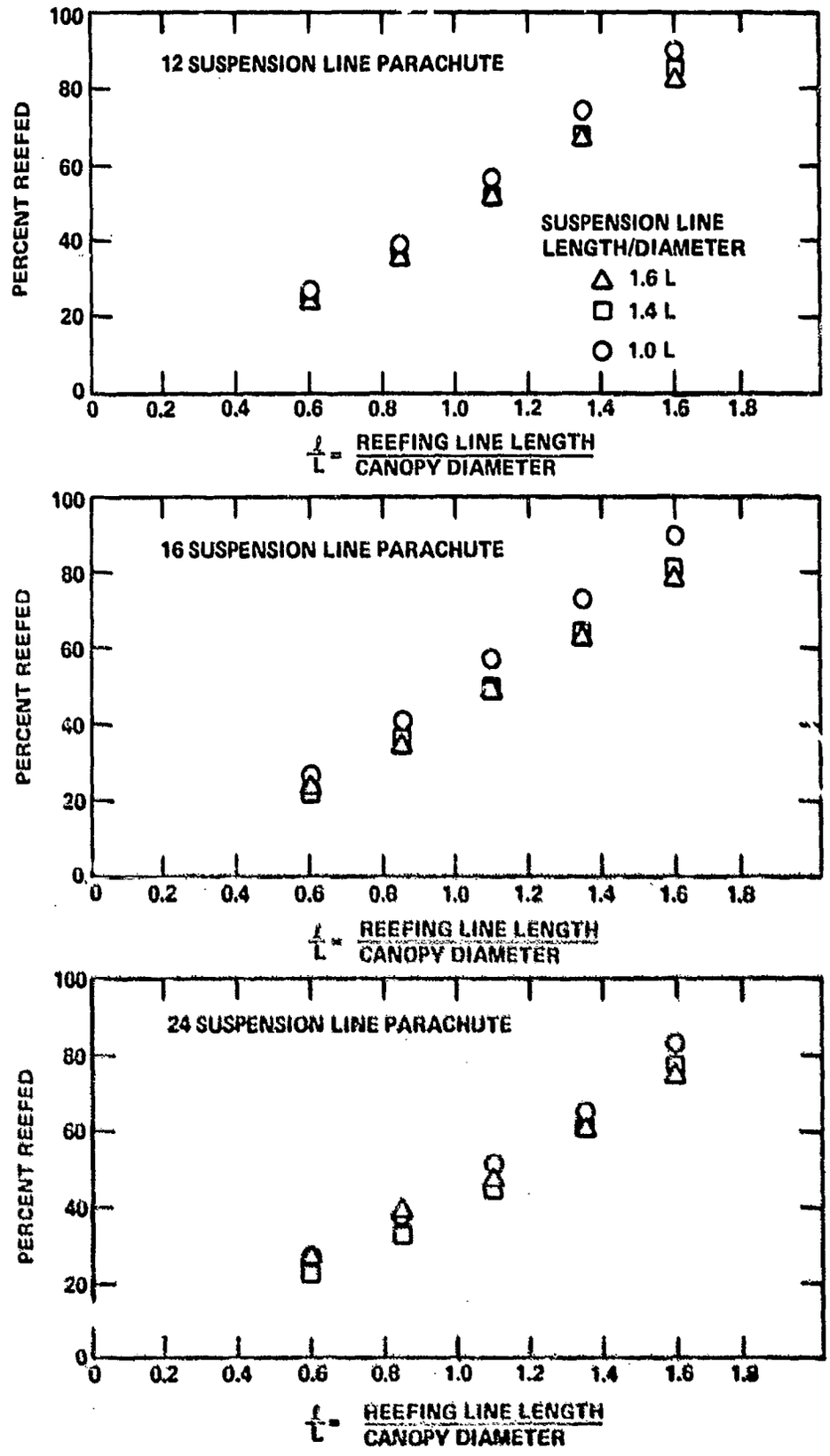


FIGURE 20 REEFED CANOPY TEST DATA CANOPY CLOTH PERMEABILITY = 98 CFM/FT^2 TEST VELOCITY = 293 FPS

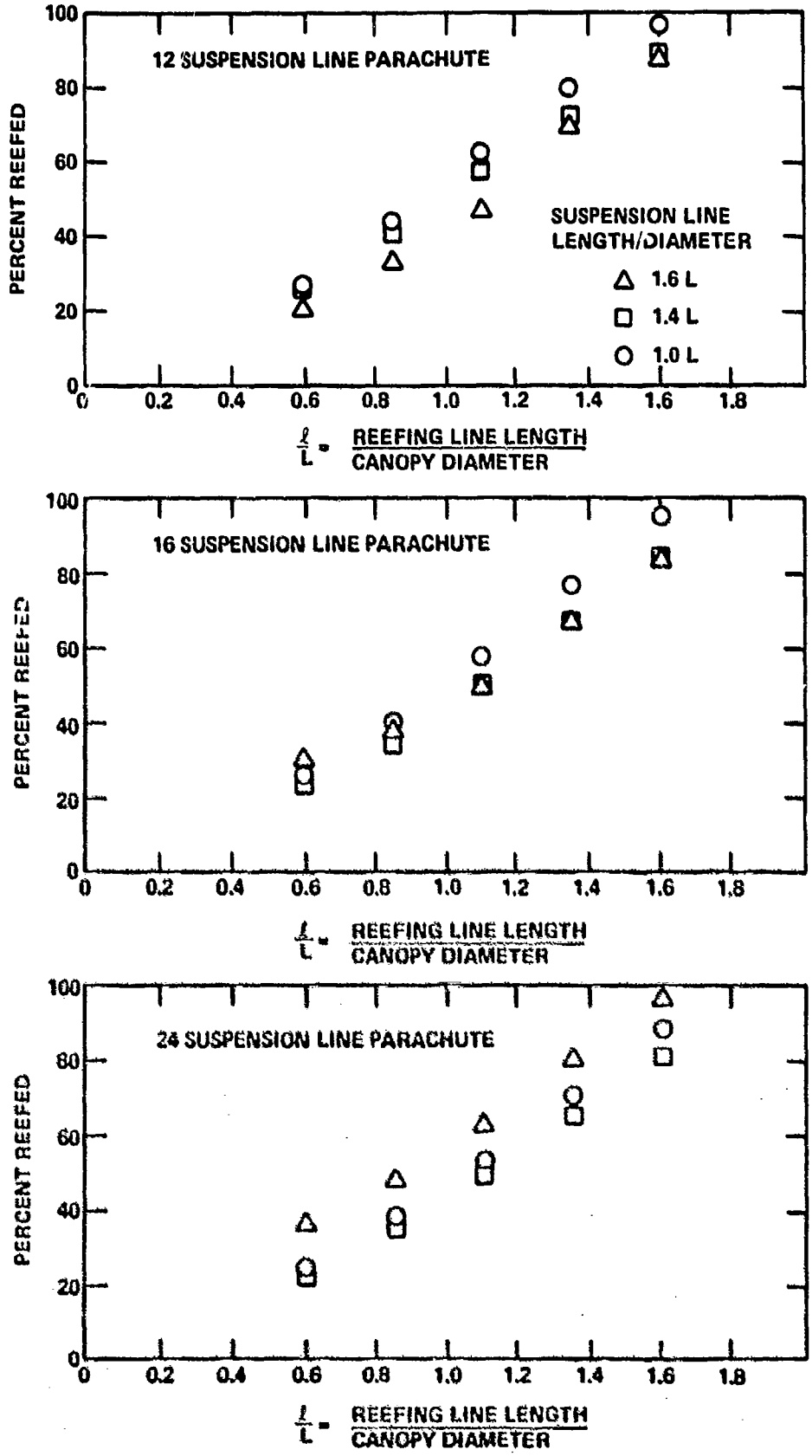


FIGURE 21 REEFED CANOPY TEST DATA CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2 TEST VELOCITY = 293 FPS

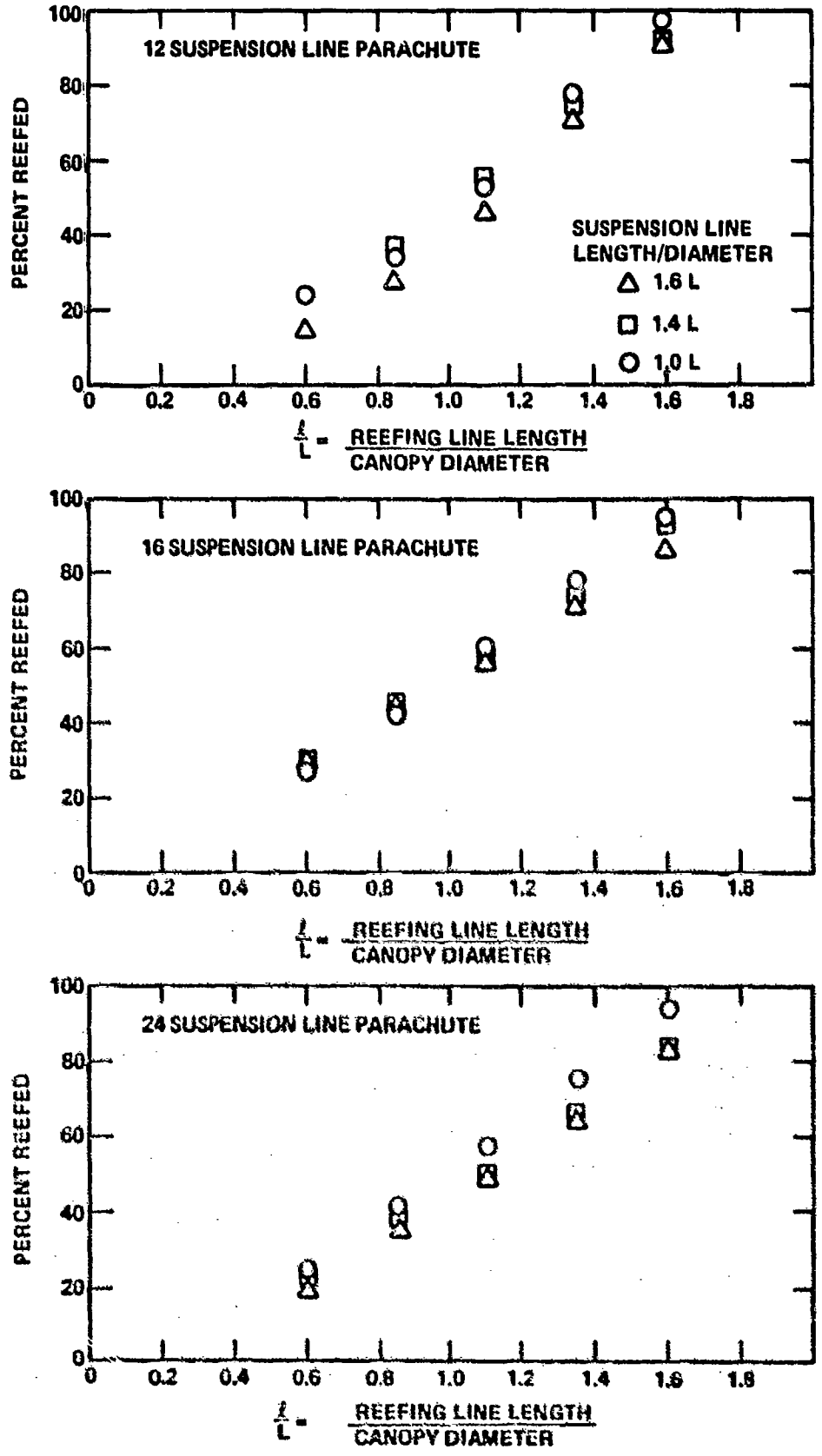


FIGURE 22 REEFED CANOPY TEST DATA CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2 TEST VELOCITY = 293 FPS

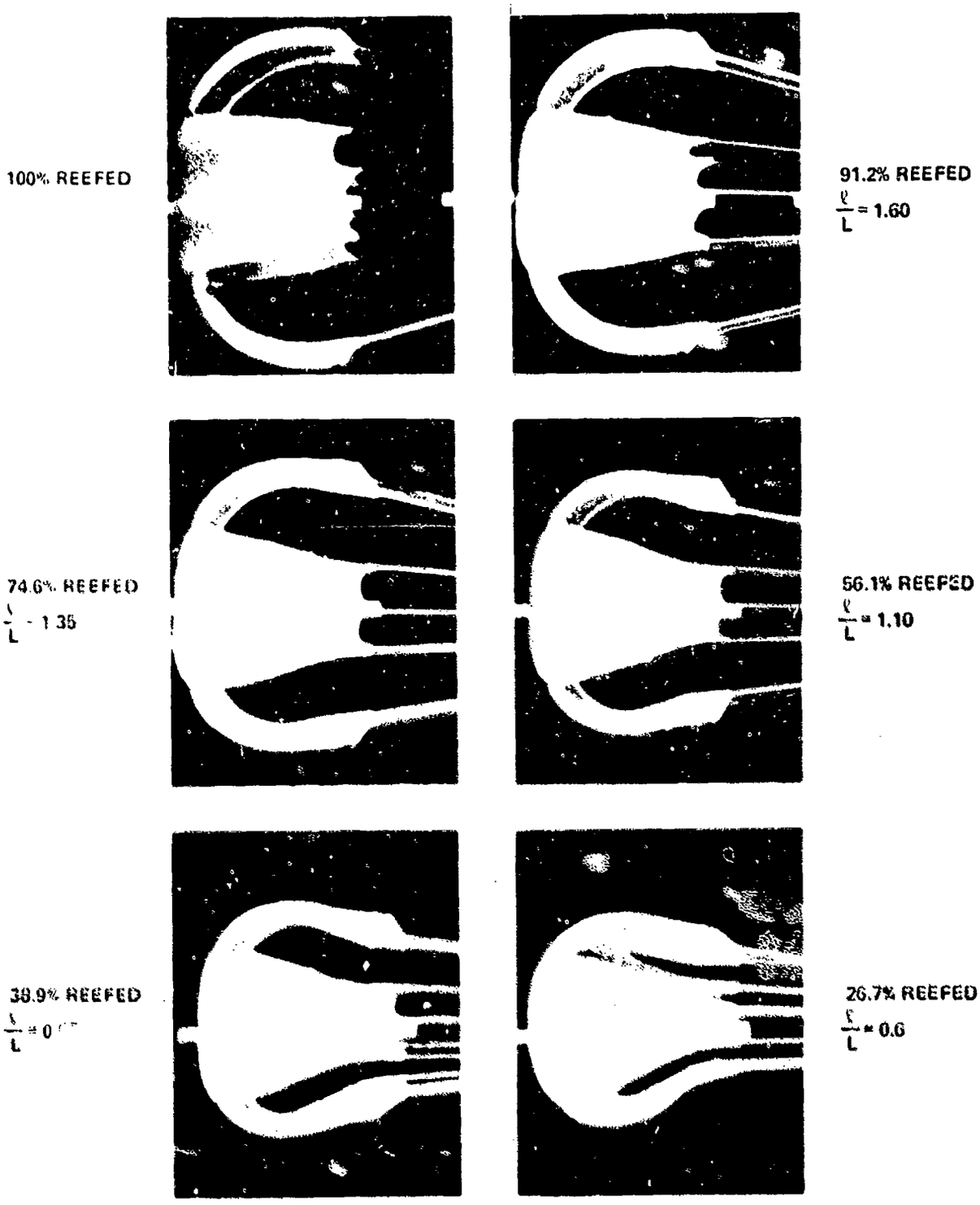


FIGURE 23 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 233 FPS

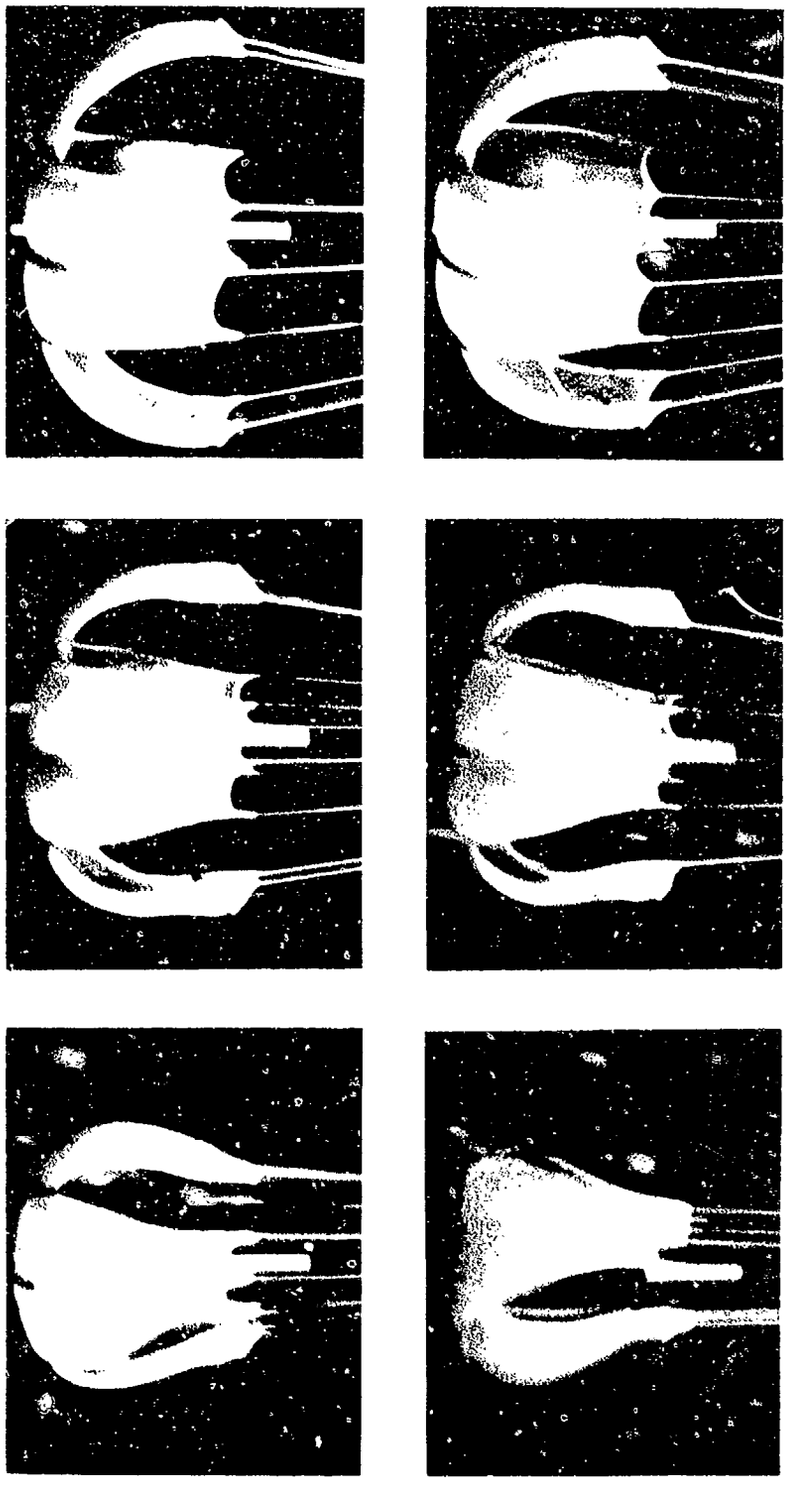


FIGURE 24 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

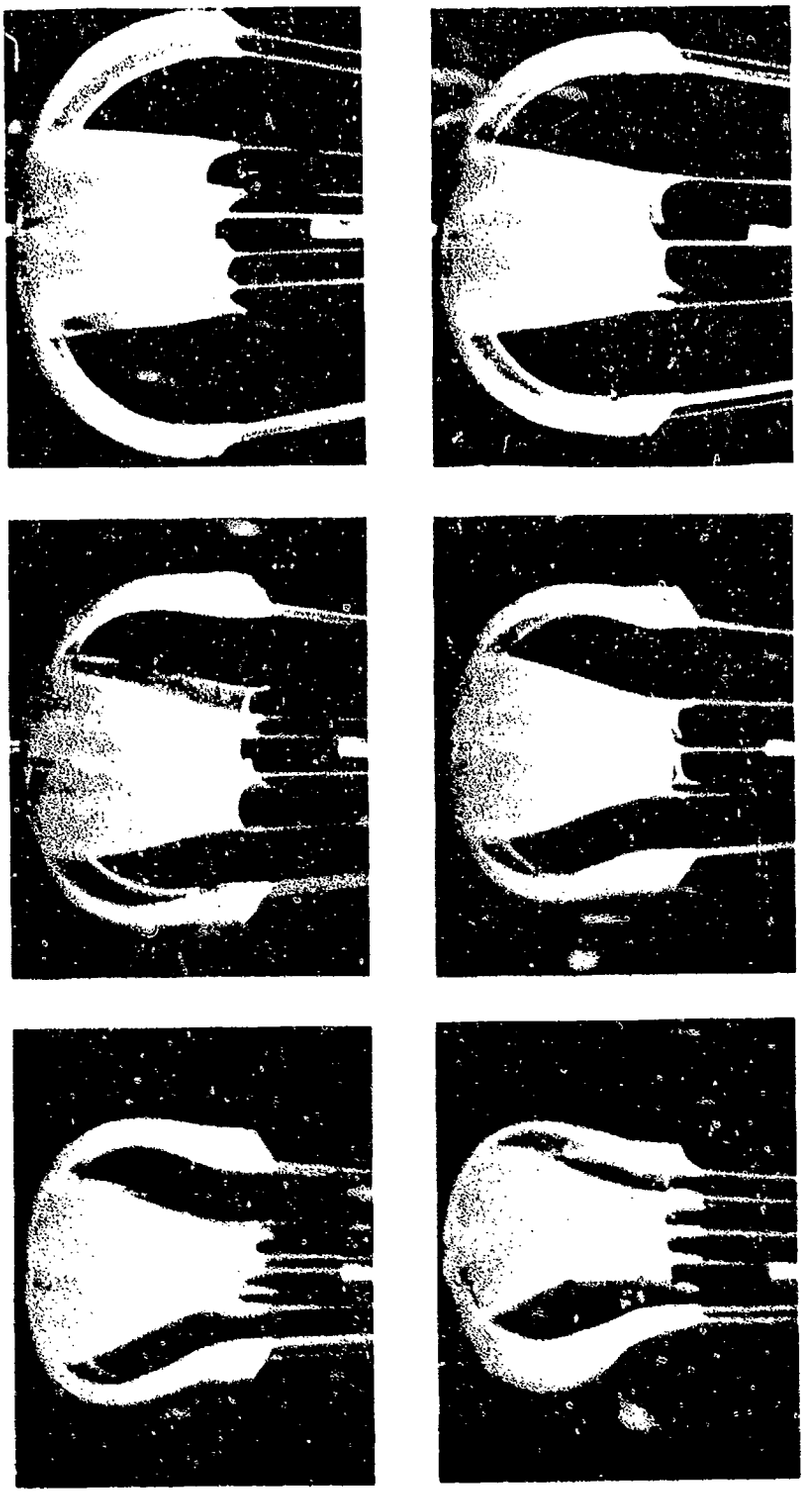


FIGURE 25 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

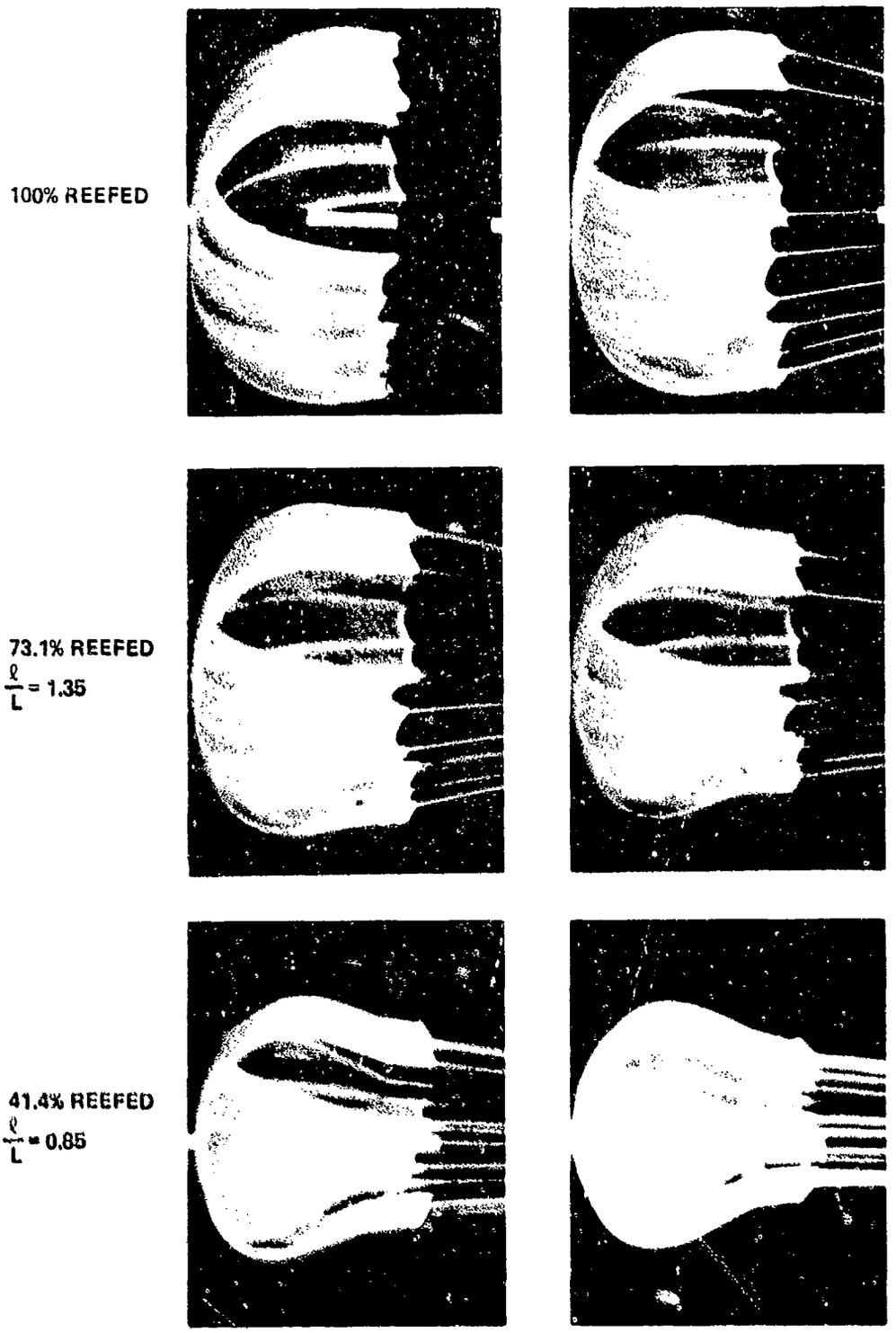


FIGURE 26 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

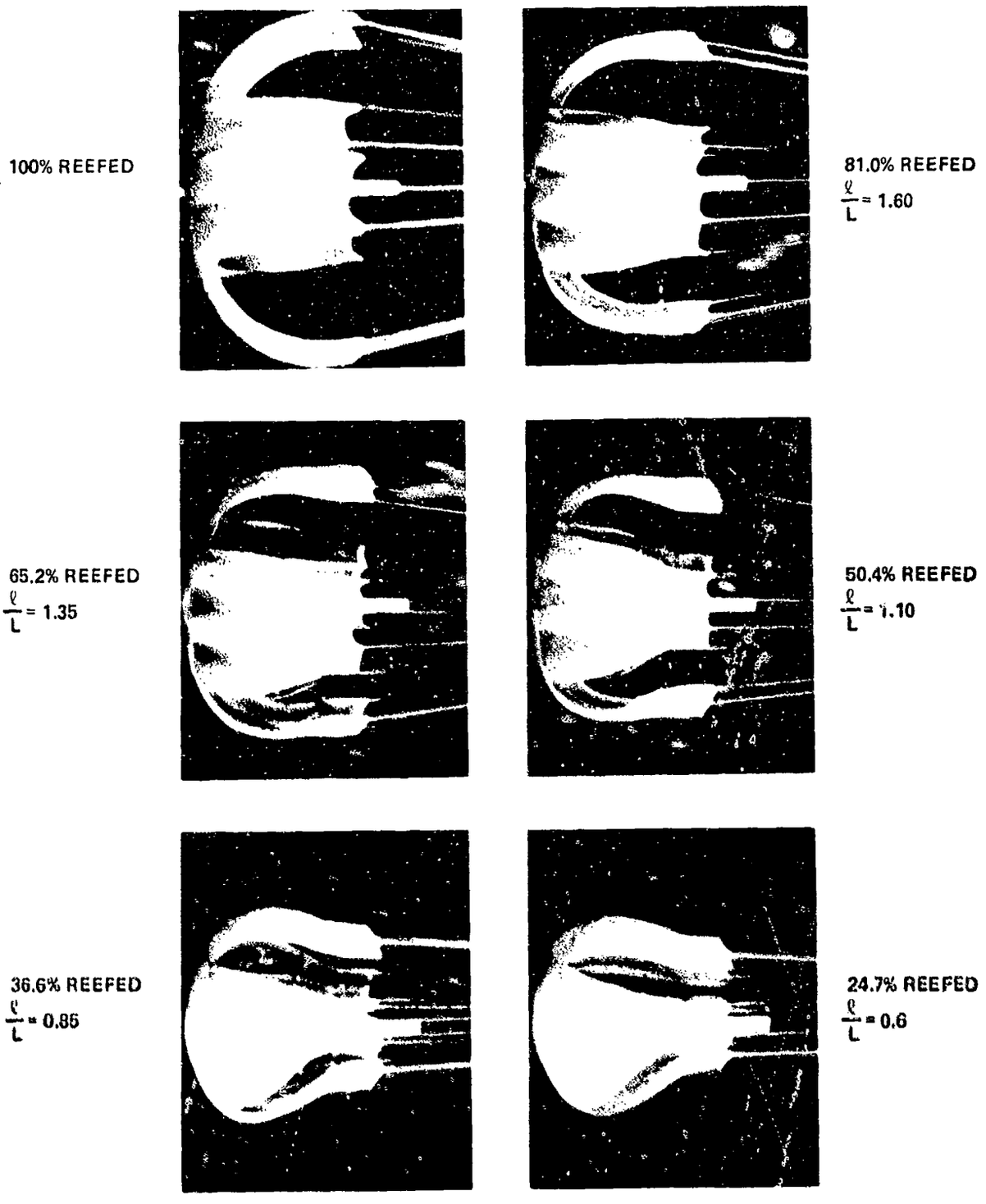


FIGURE 27 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

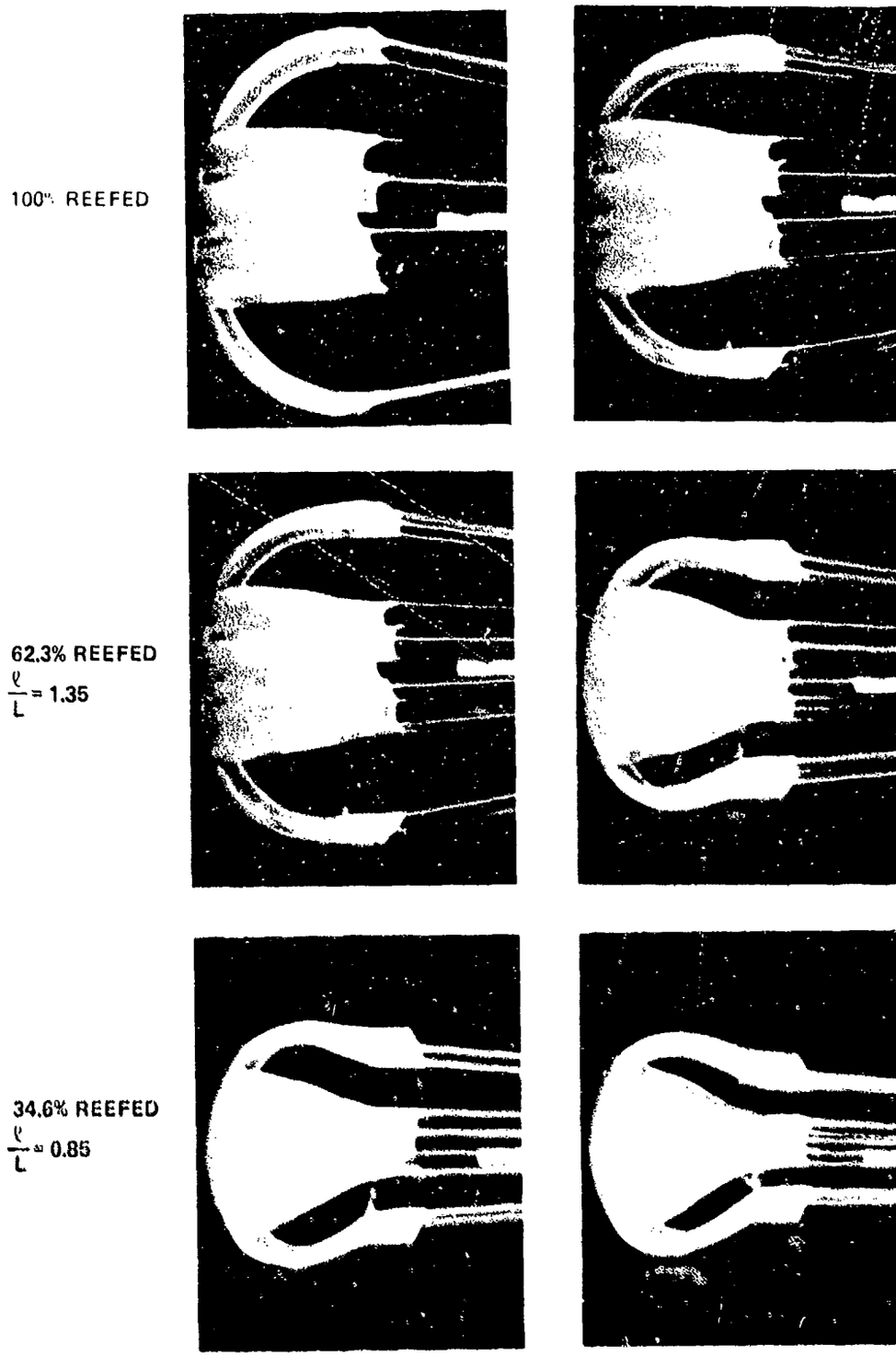


FIGURE 28 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

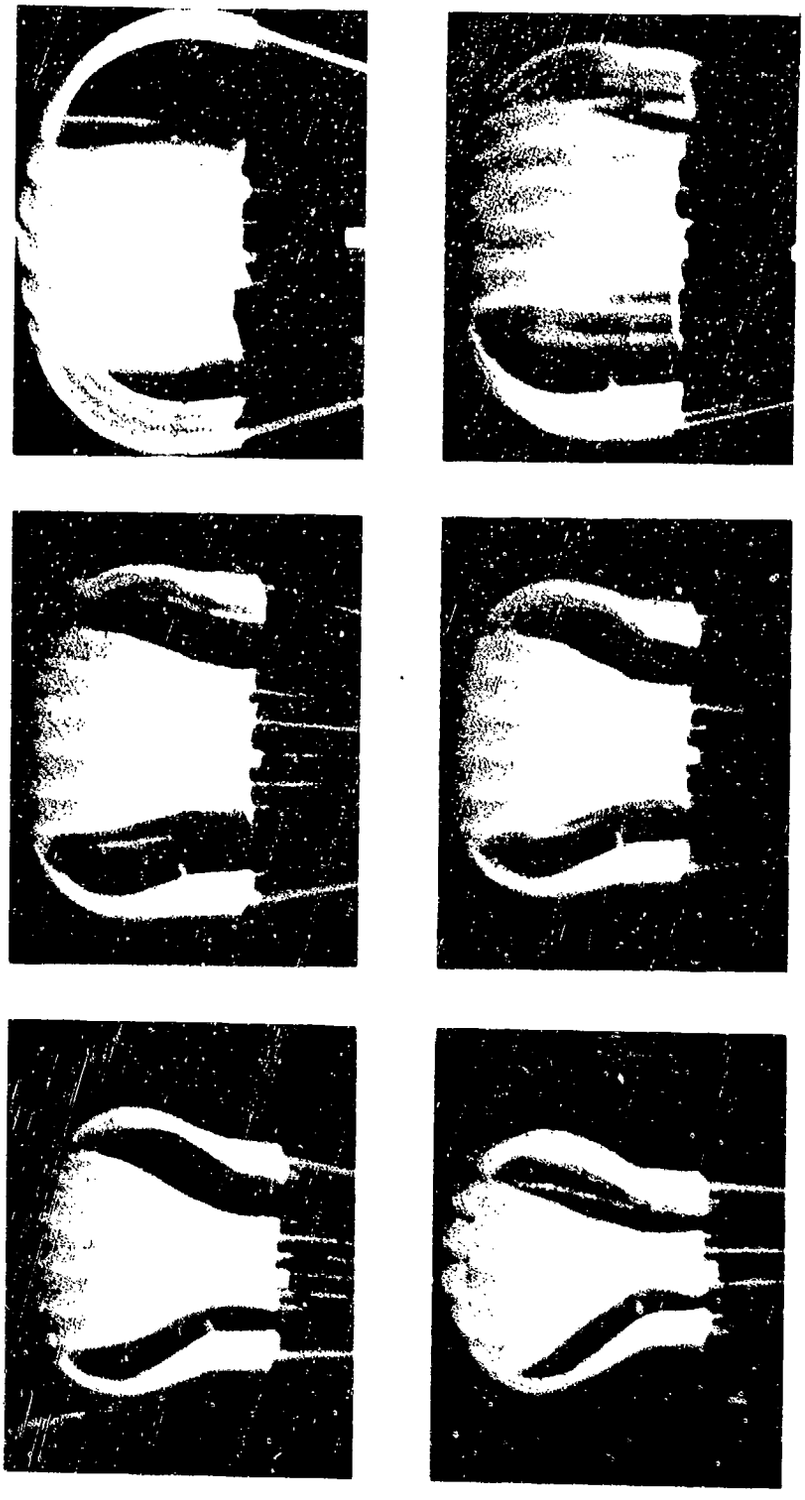


FIGURE 29 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

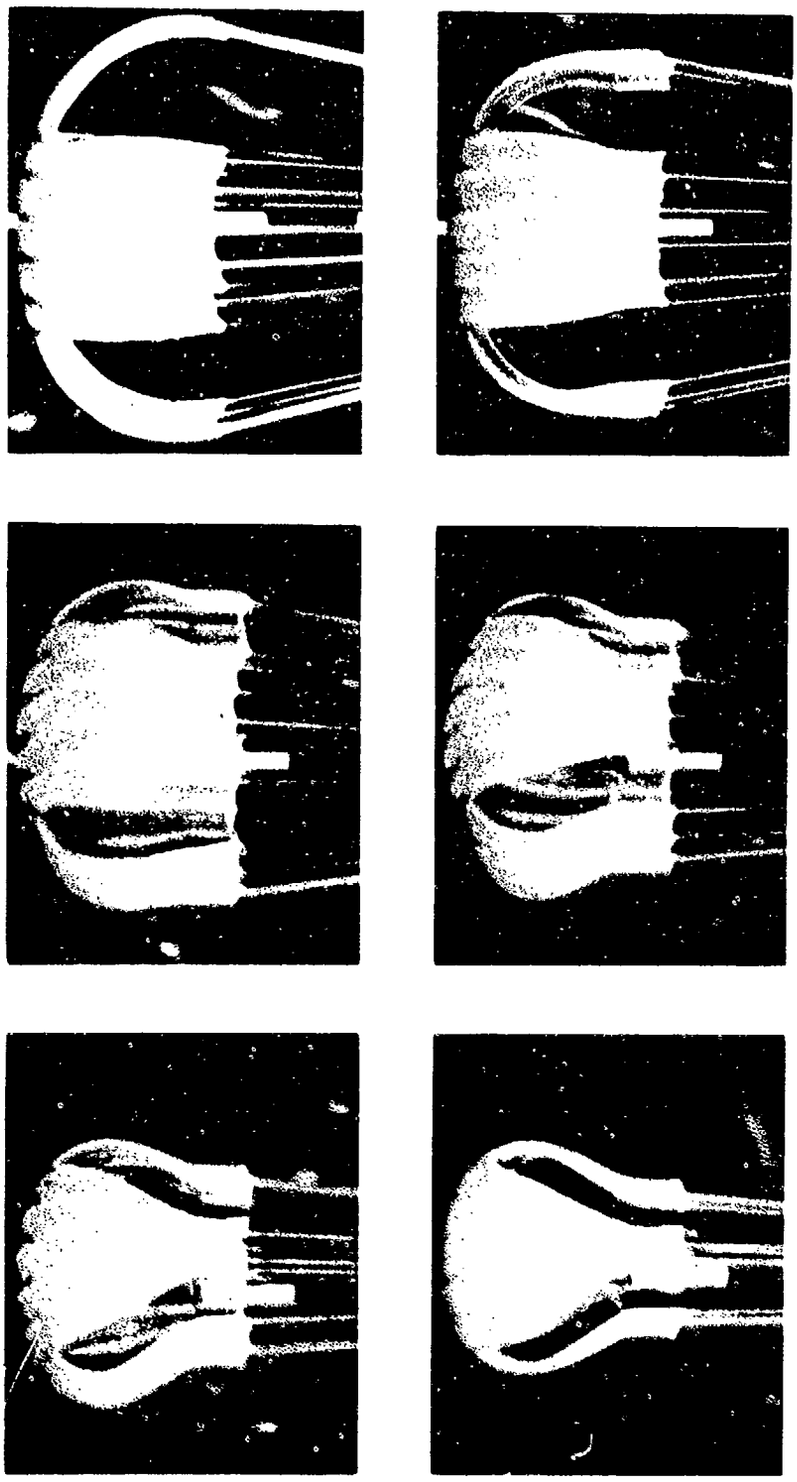


FIGURE 30 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

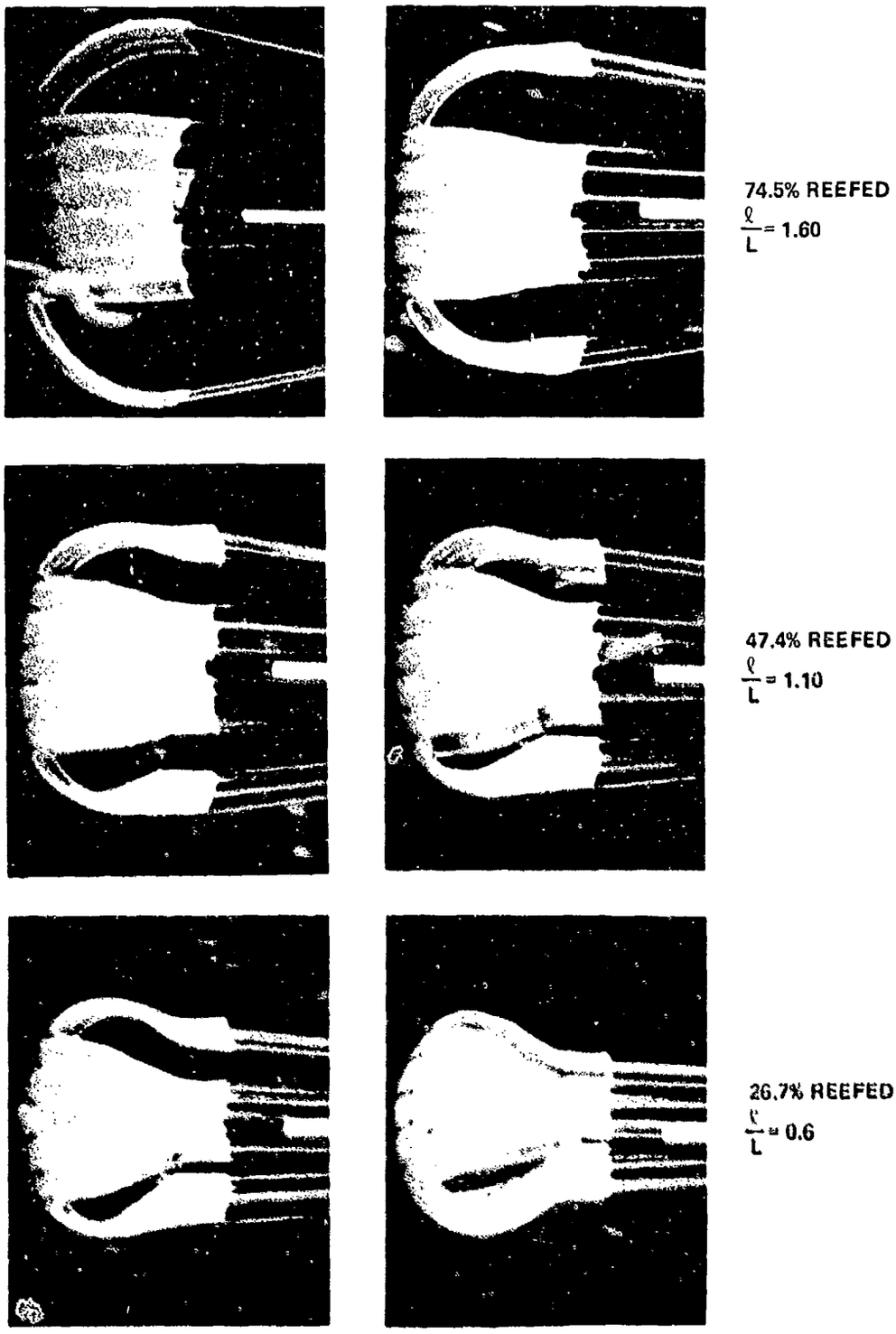


FIGURE 31 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 98 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

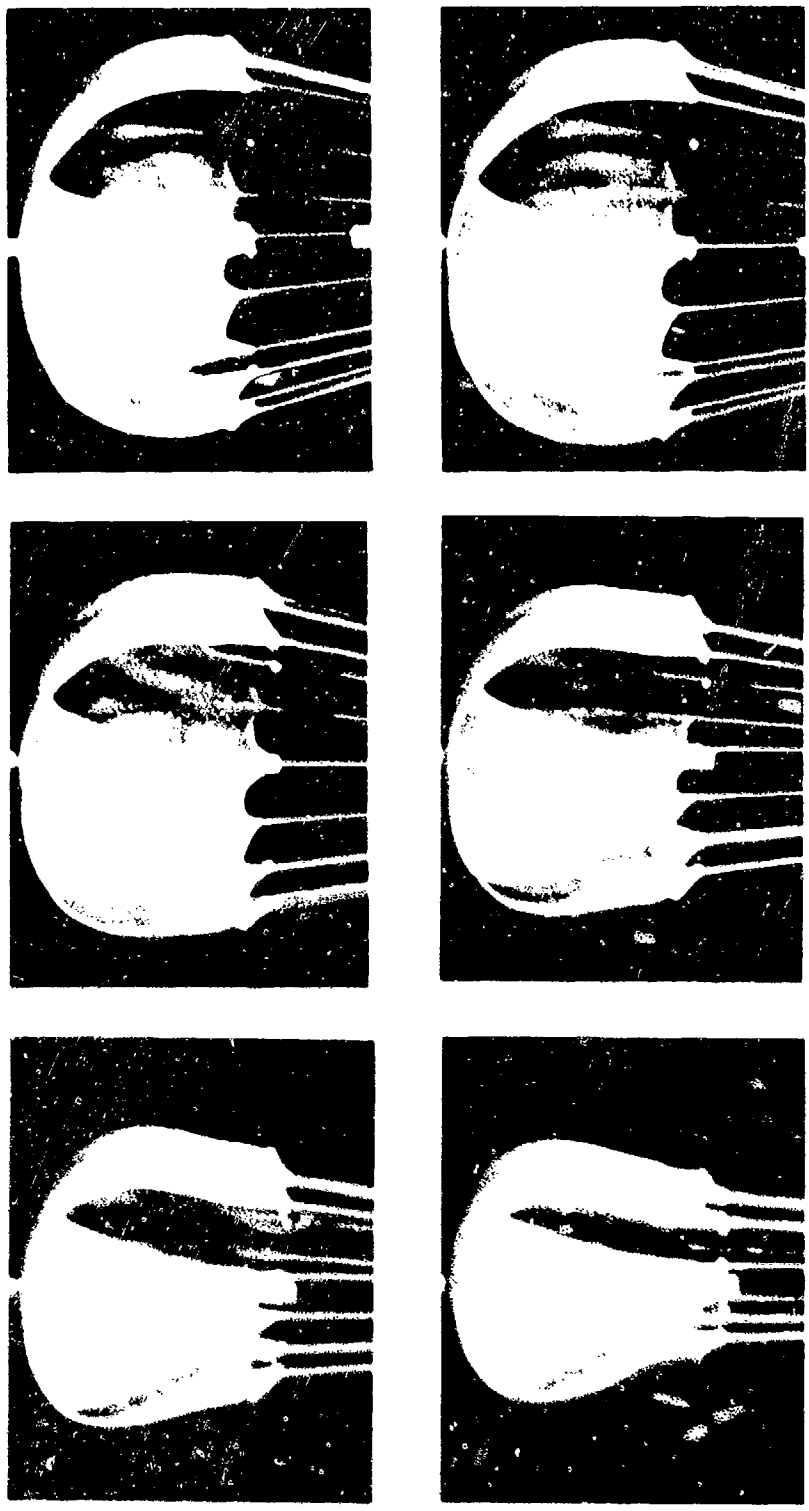


FIGURE 32 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

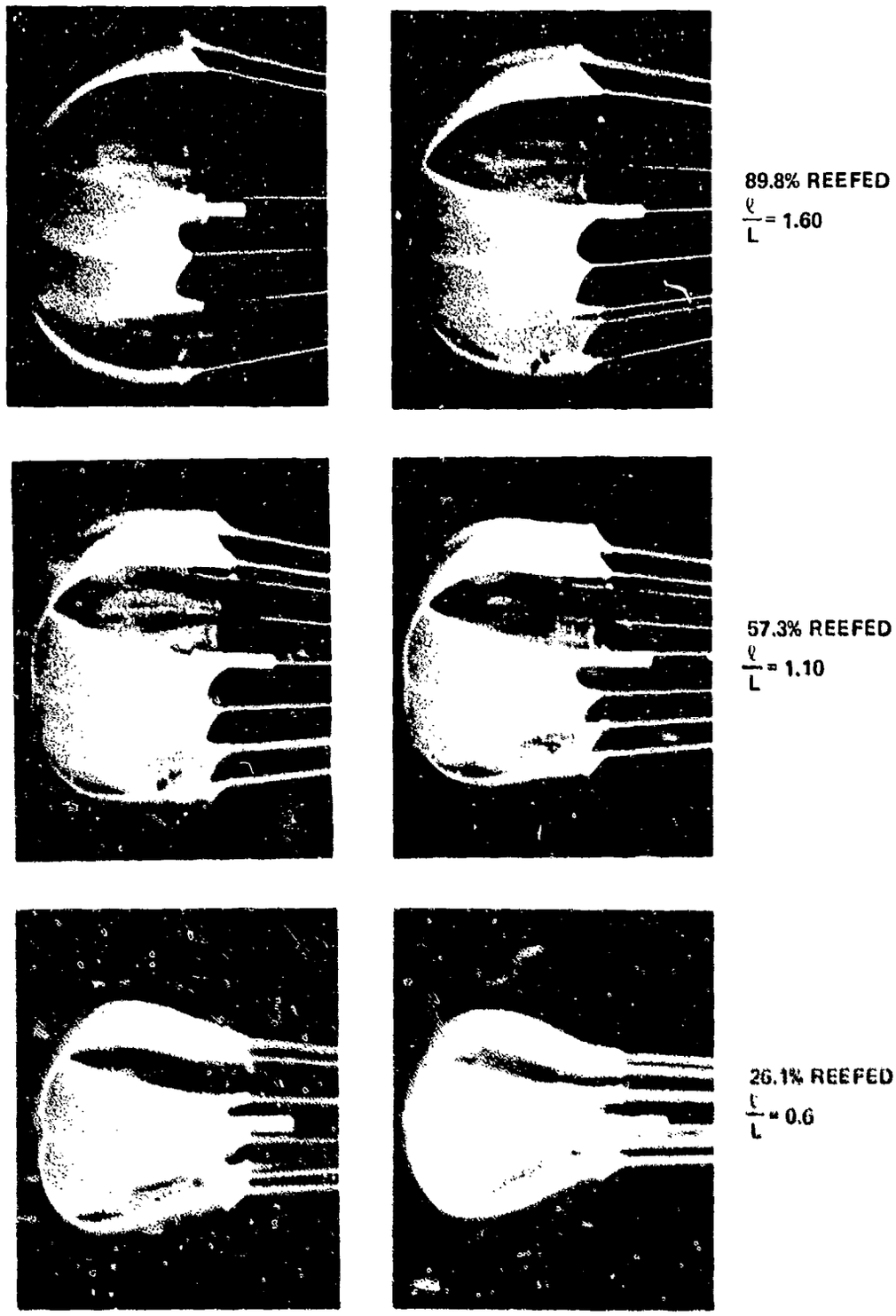


FIGURE 33 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

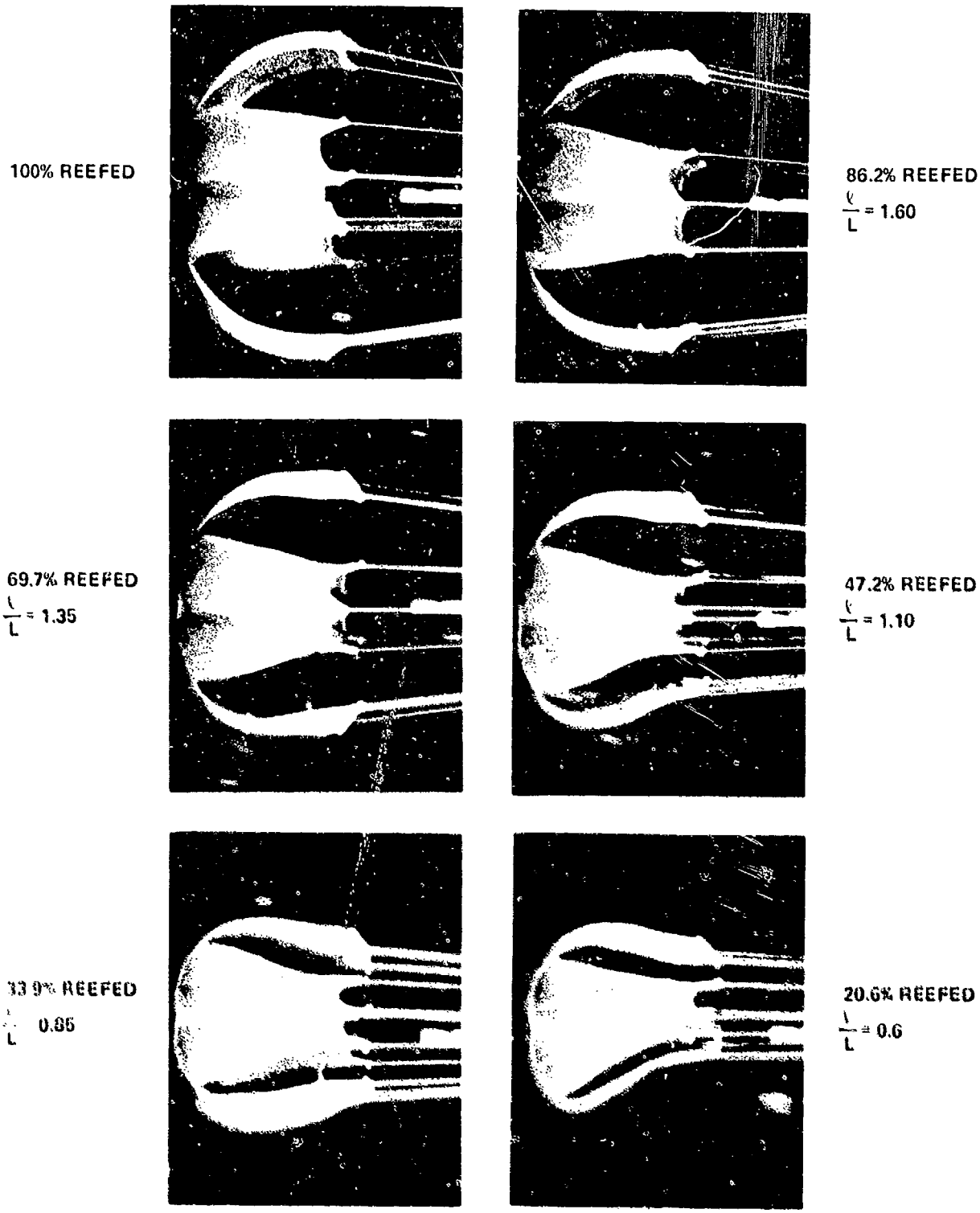


FIGURE 34 REEFED CANOPY INFLATED SHAPES, CLOTH PERMEABILITY = 225 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY ~ 293 FPS

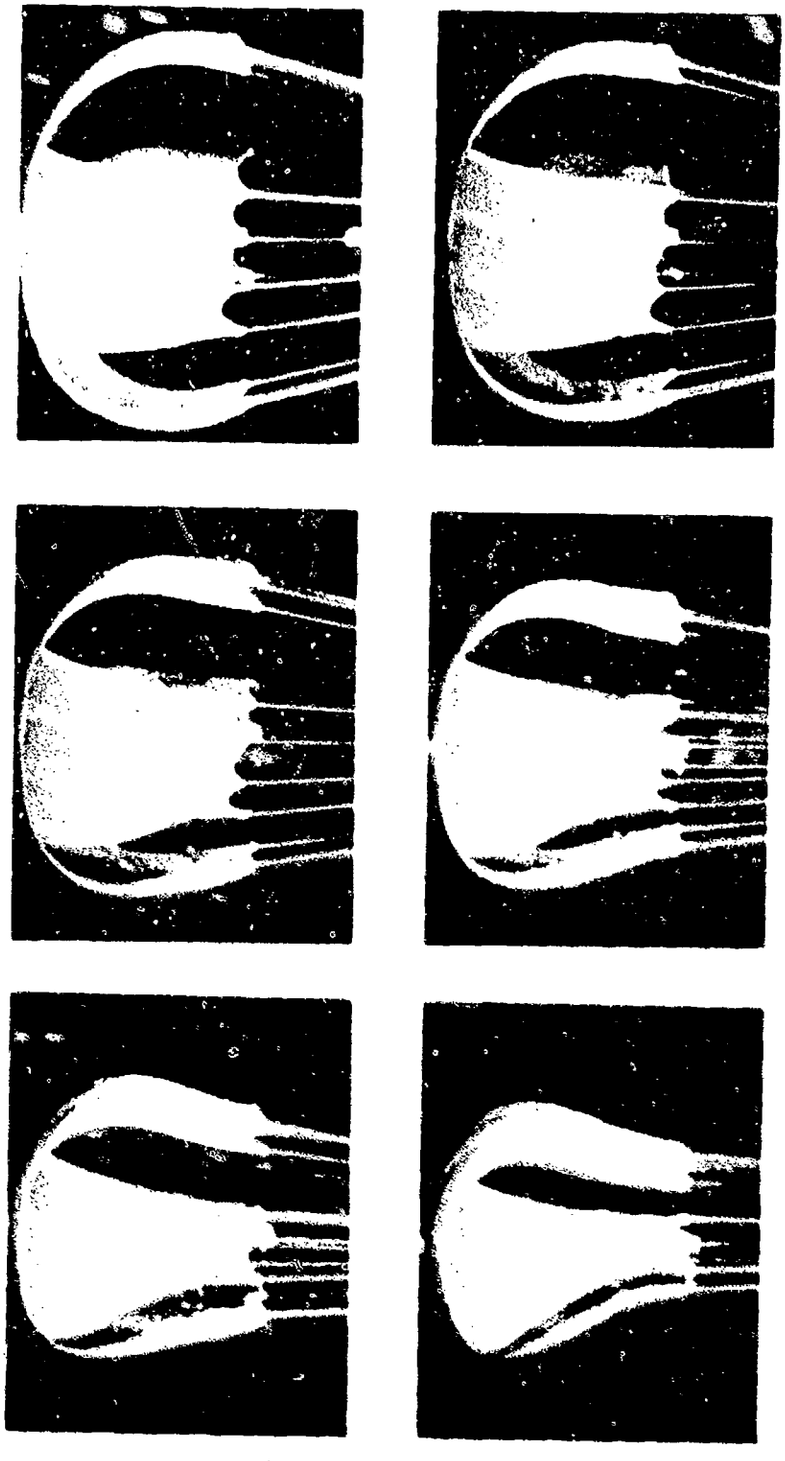


FIGURE 35 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

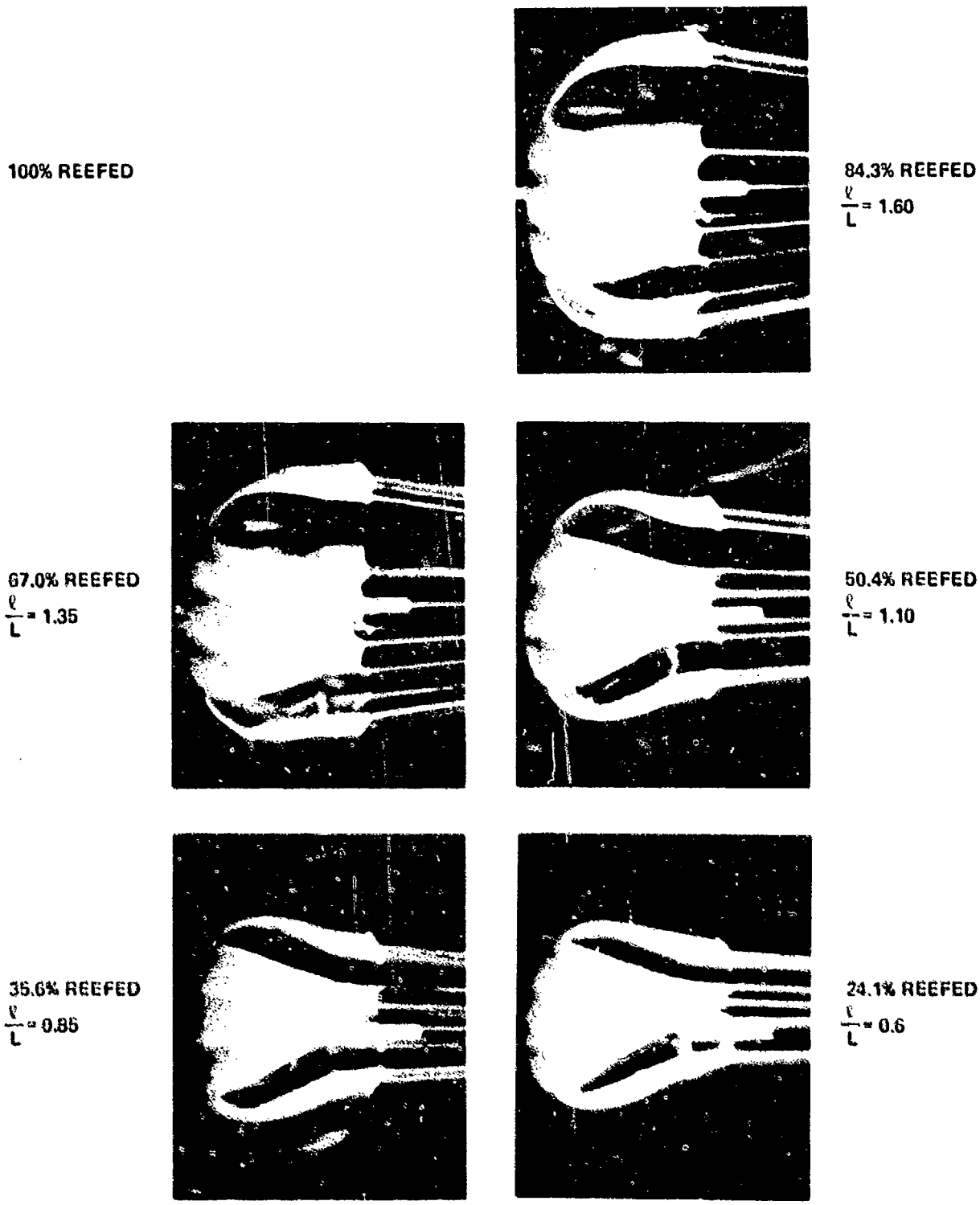


FIGURE 36 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

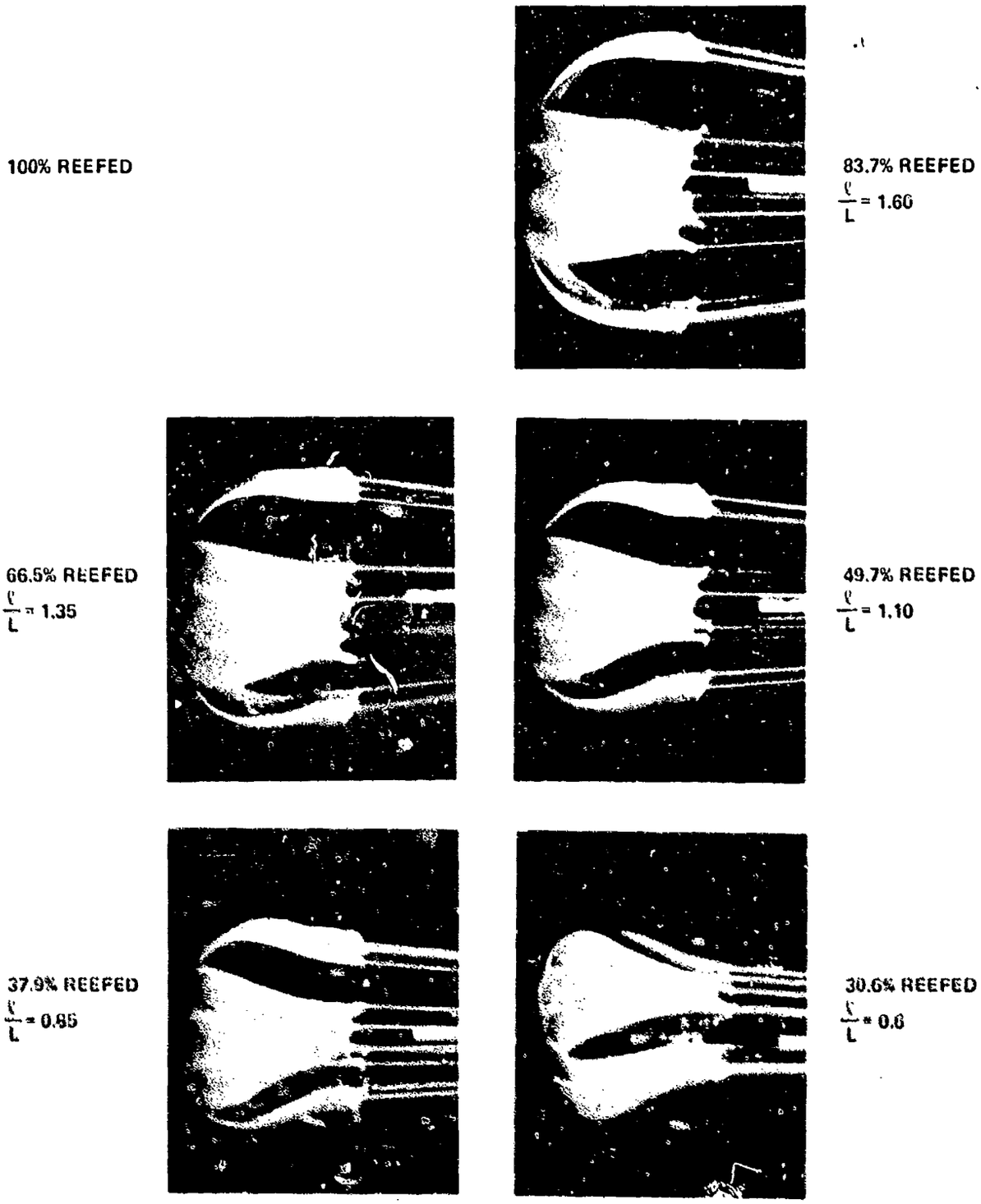


FIGURE 37 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

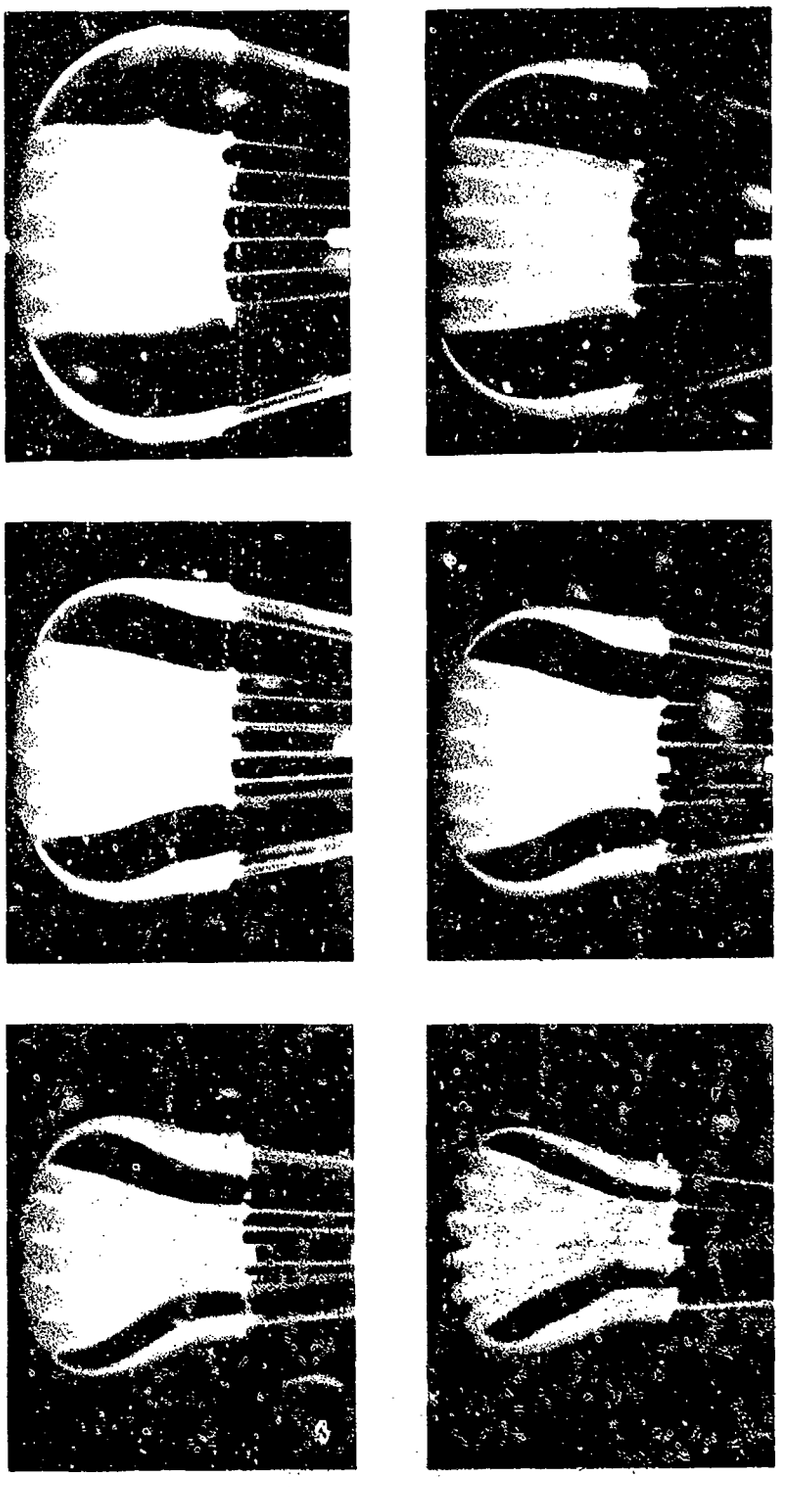


FIGURE 38 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

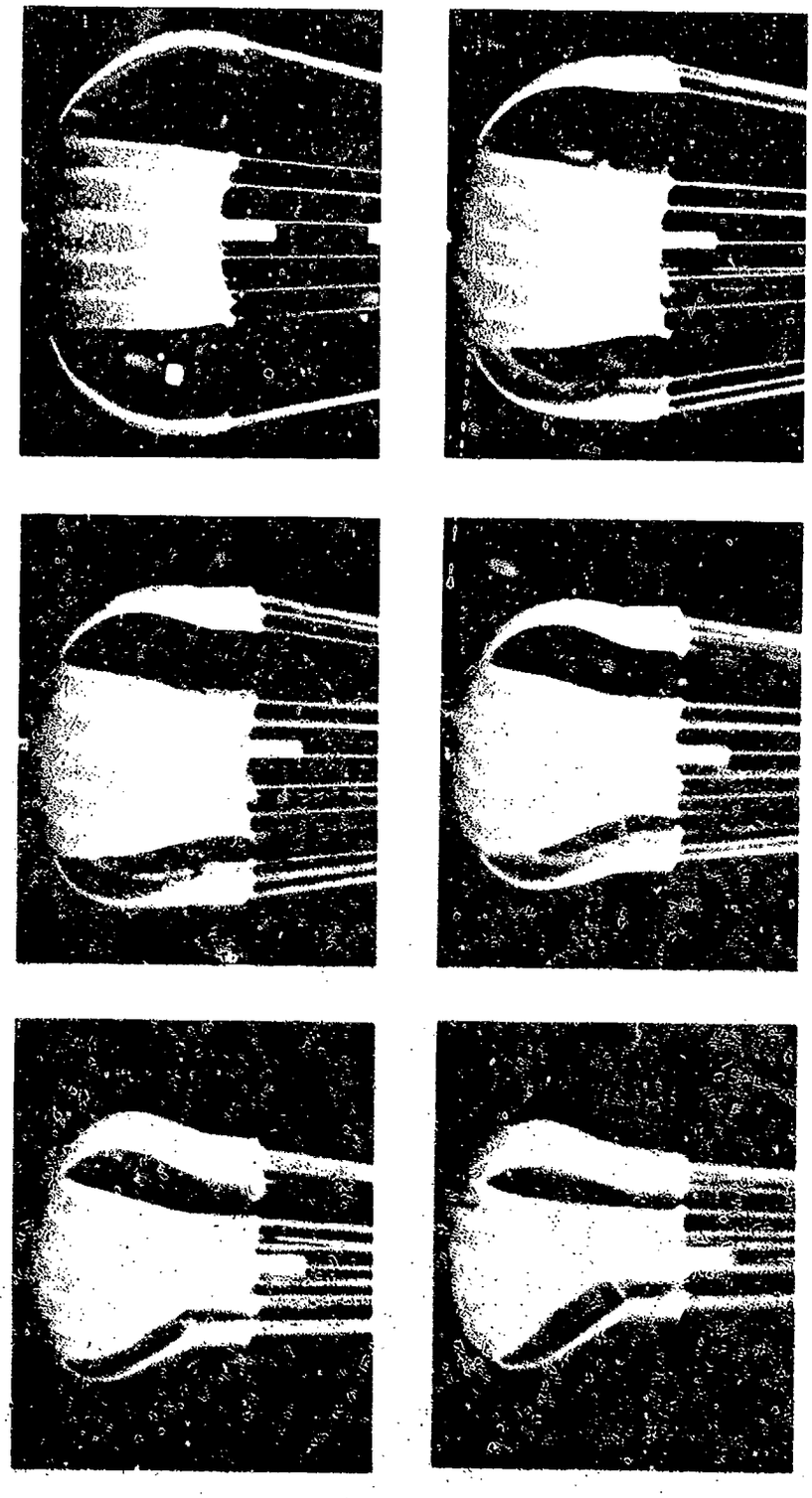


FIGURE 39 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

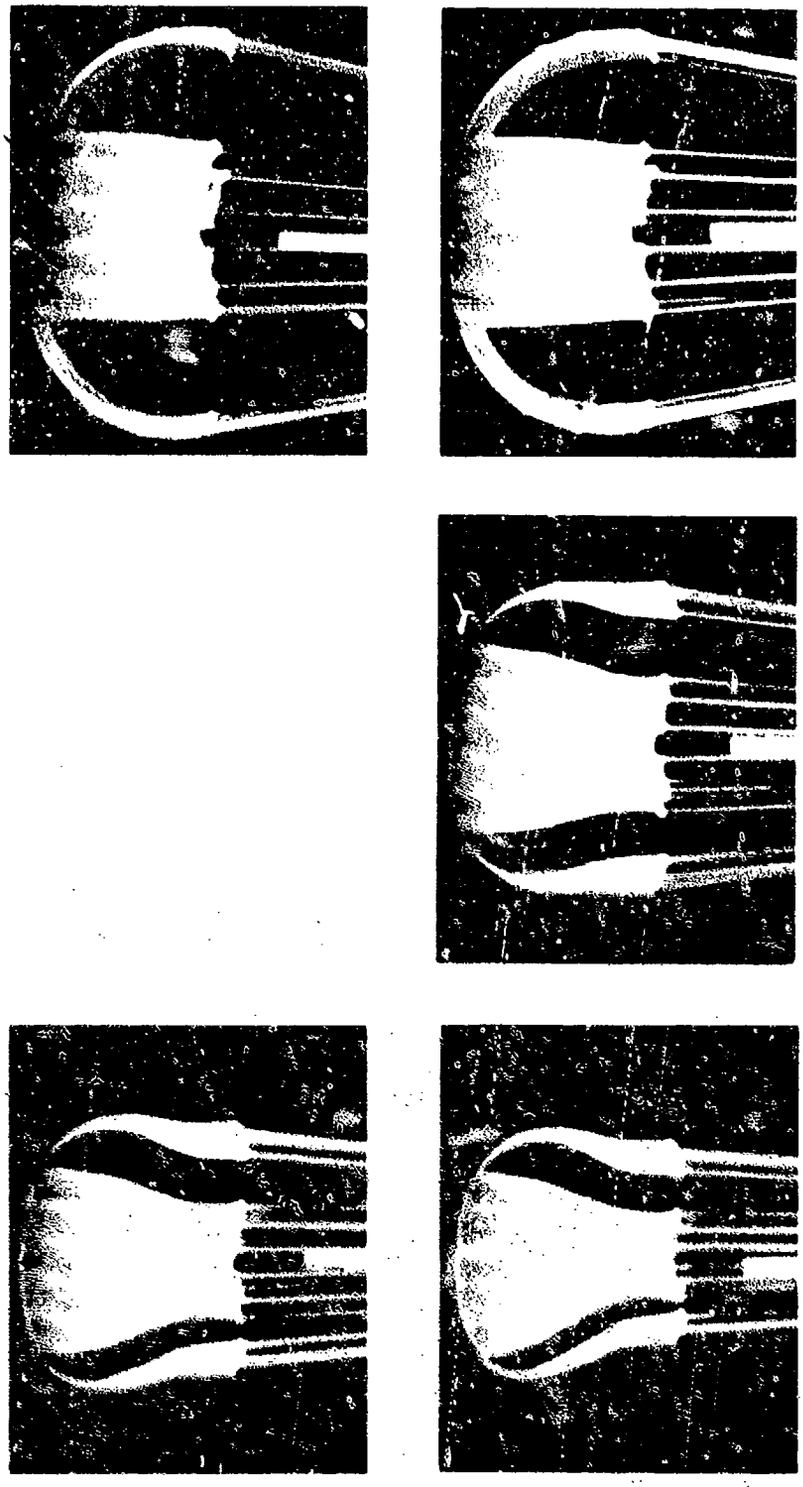


FIGURE 40 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 225 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

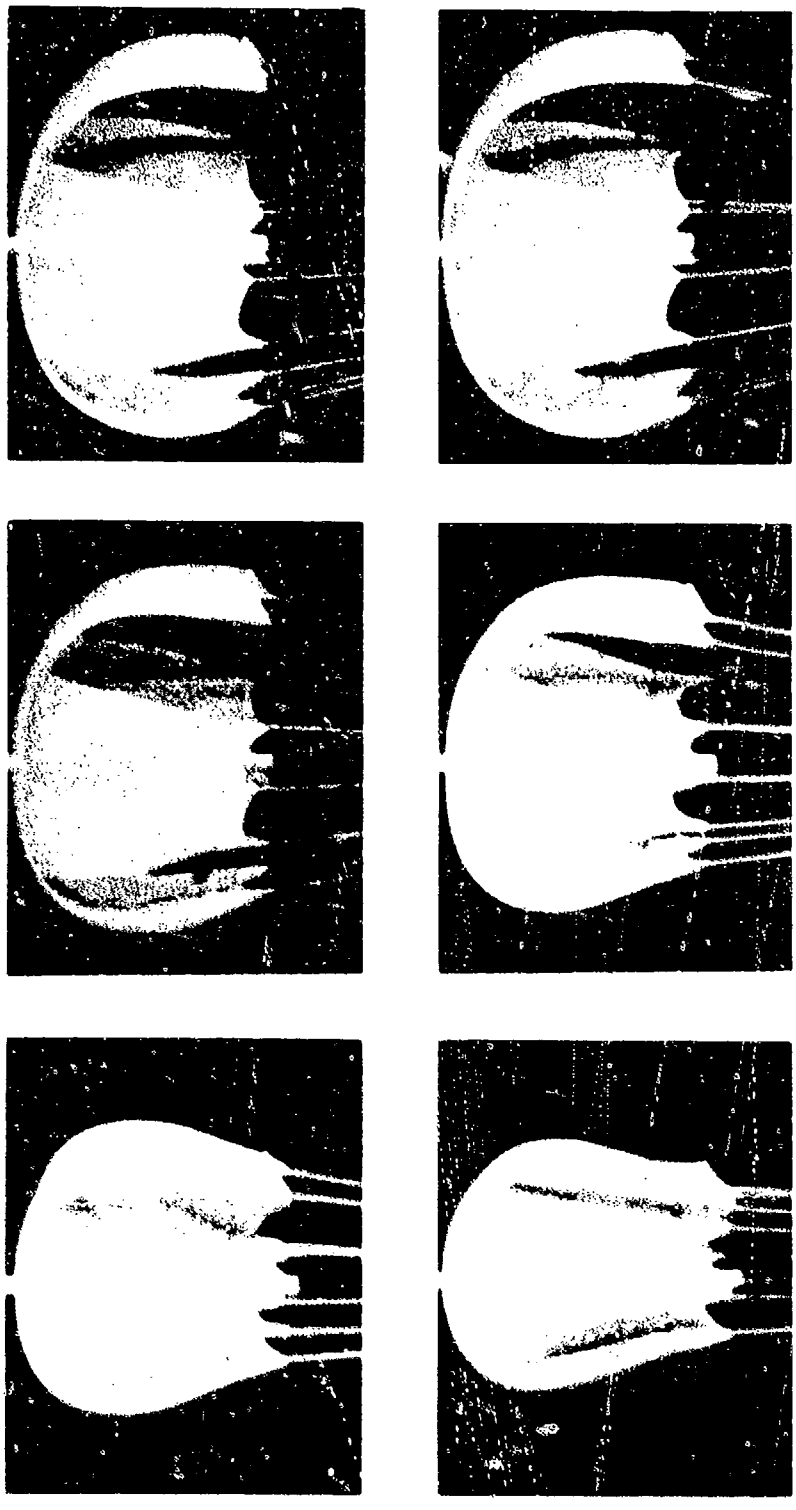


FIGURE 41 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

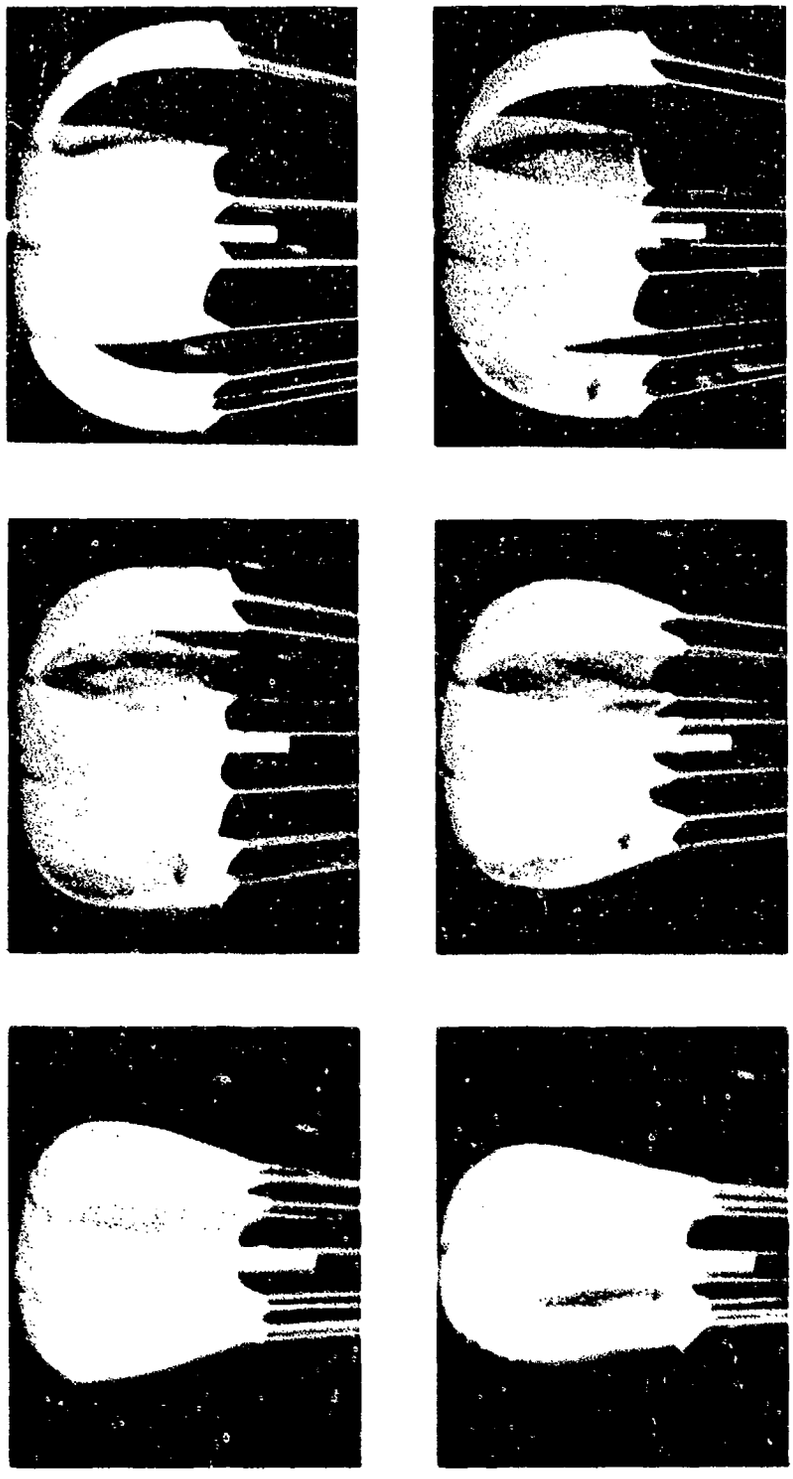


FIGURE 42 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

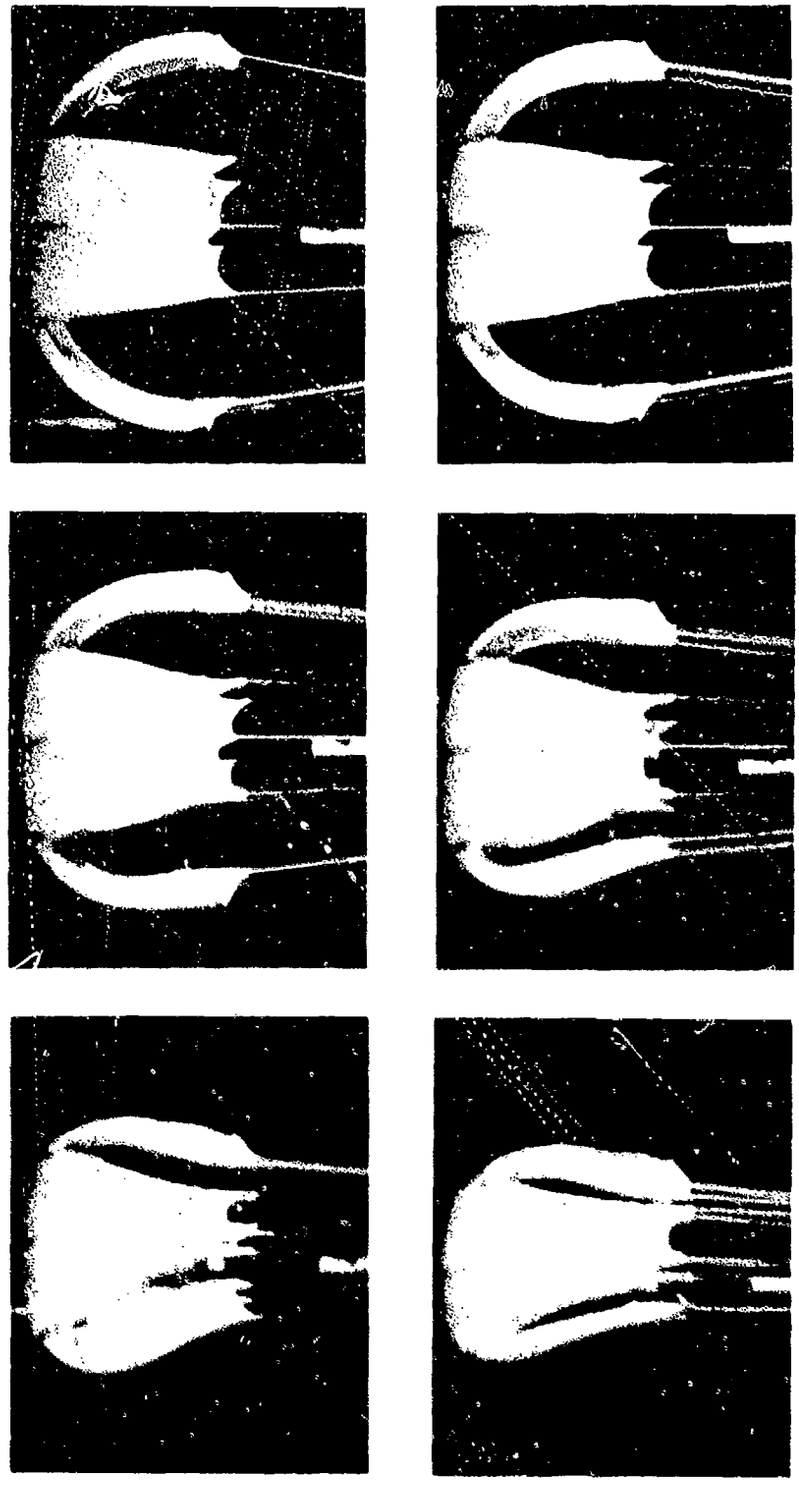


FIGURE 43 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 12 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

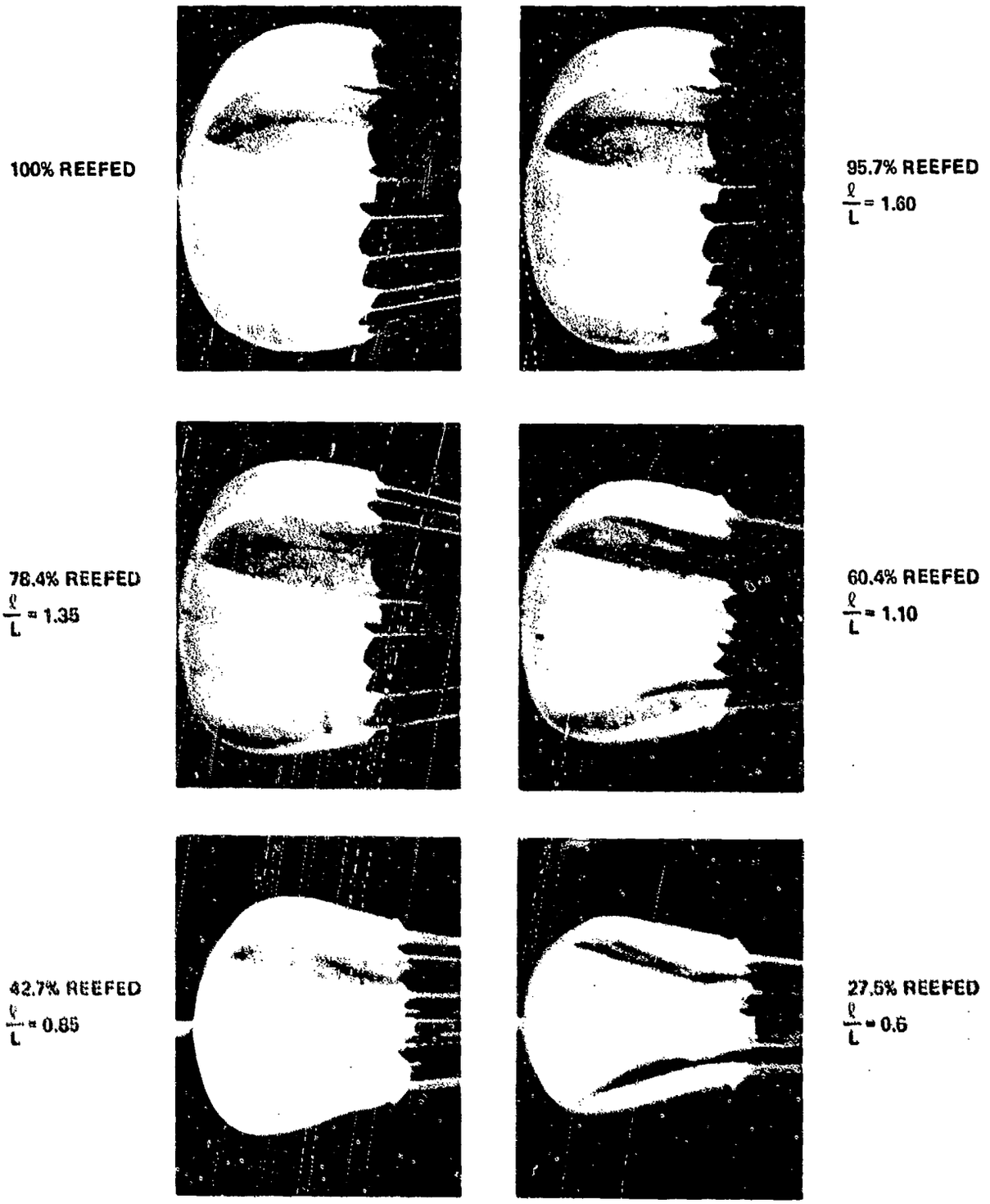


FIGURE 44 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

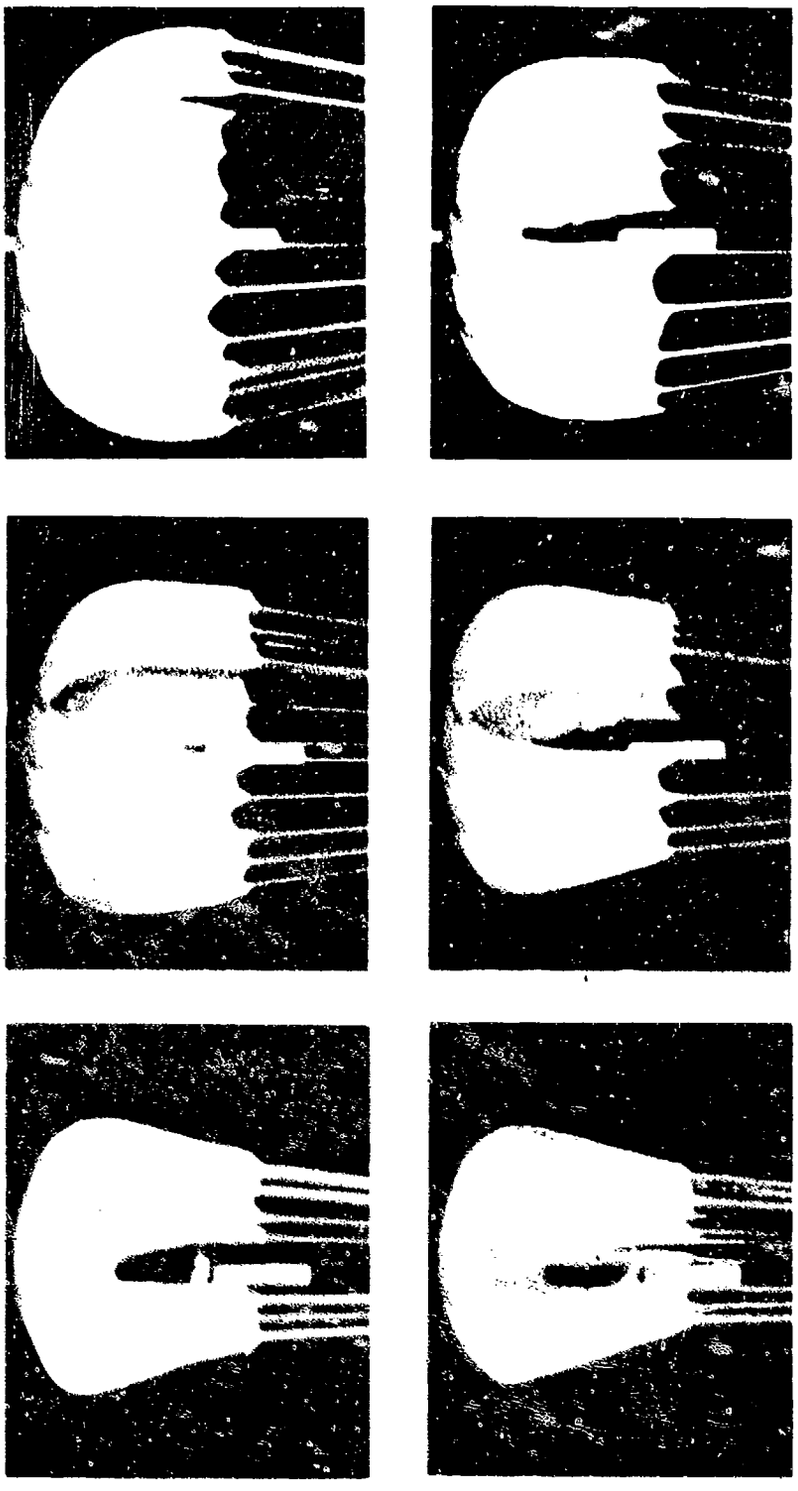


FIGURE 45 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

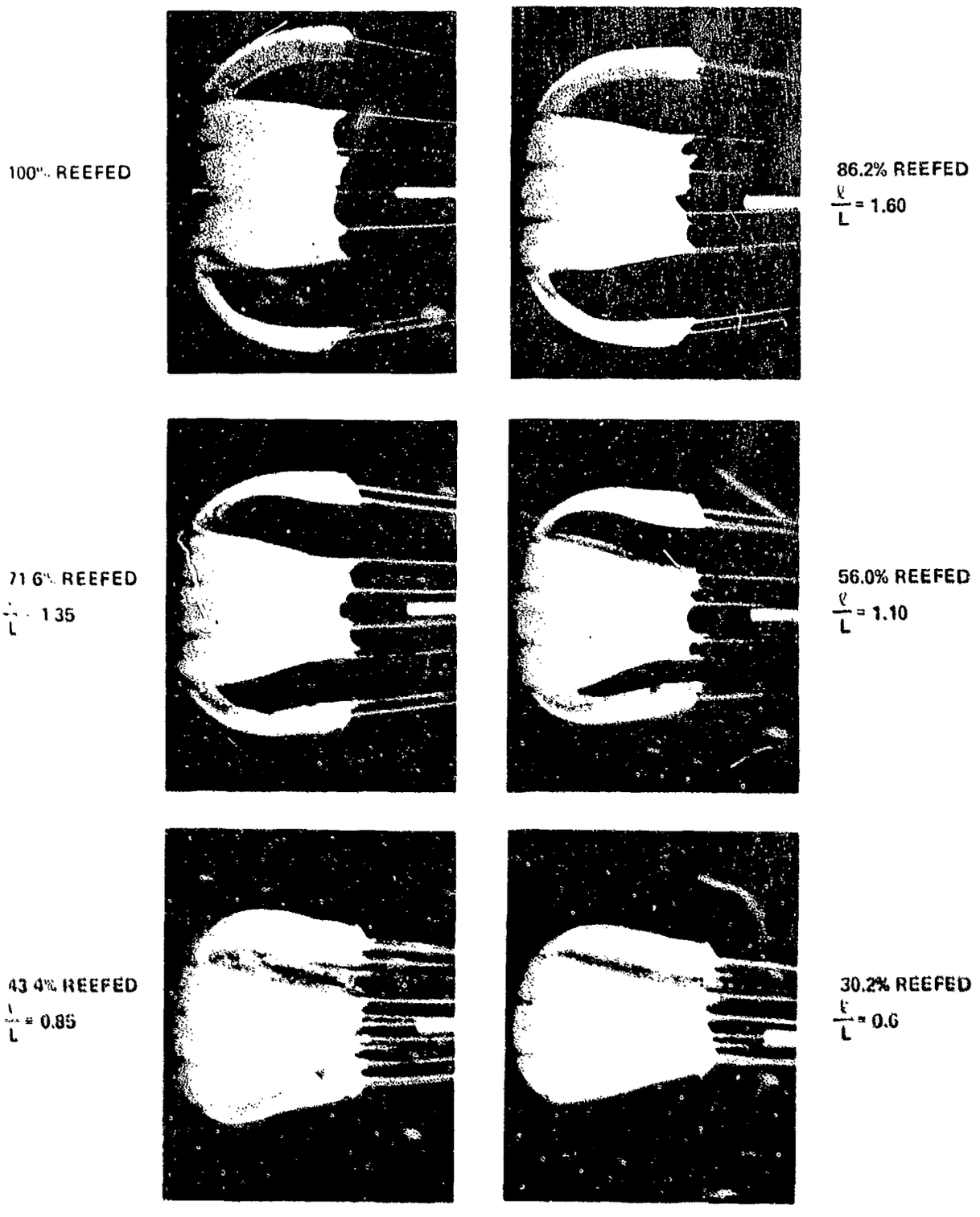


FIGURE 46 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 16 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

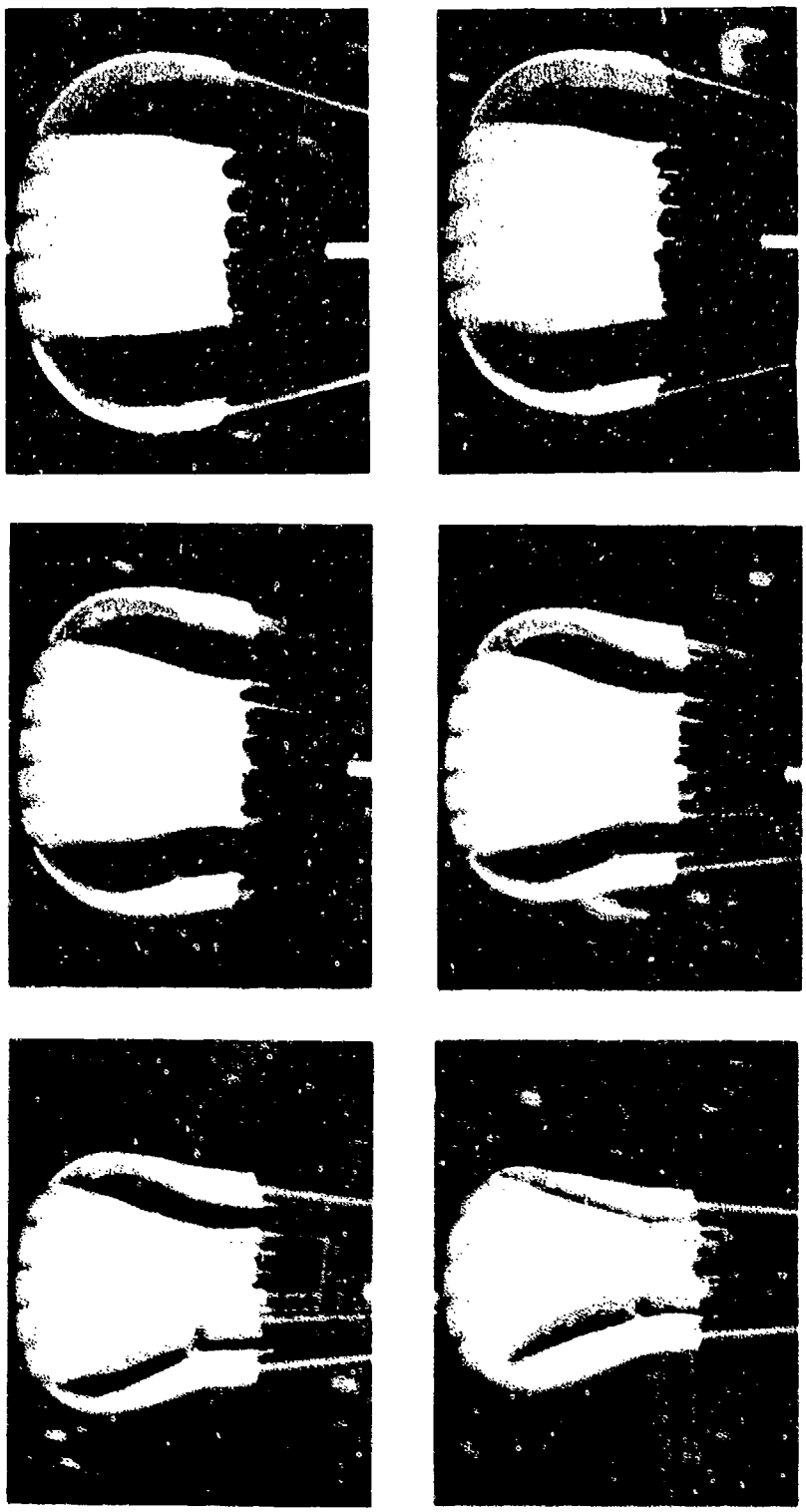


FIGURE 47 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.0 L; TEST VELOCITY = 293 FPS

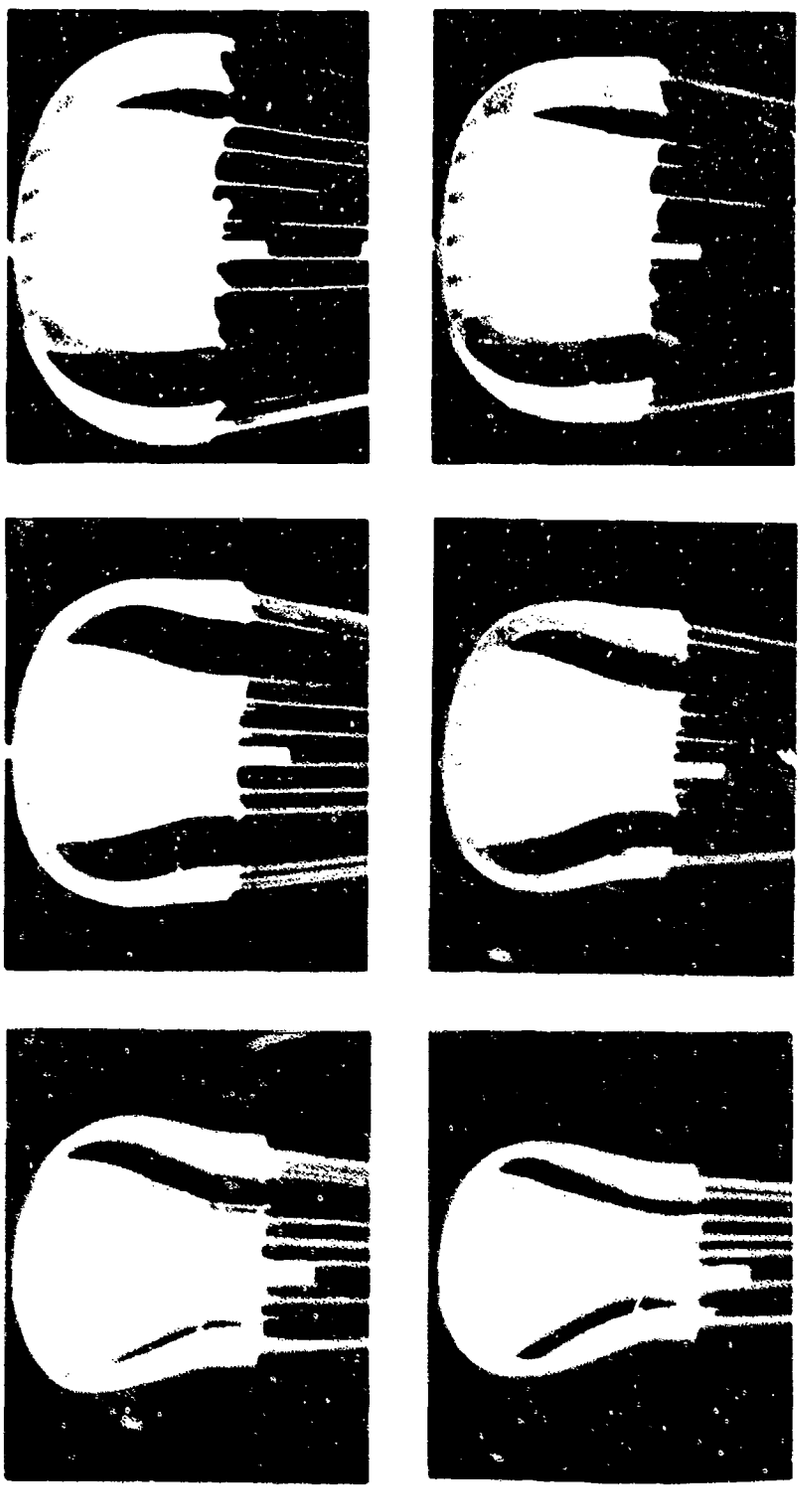


FIGURE 48 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2, 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.4 L; TEST VELOCITY = 293 FPS

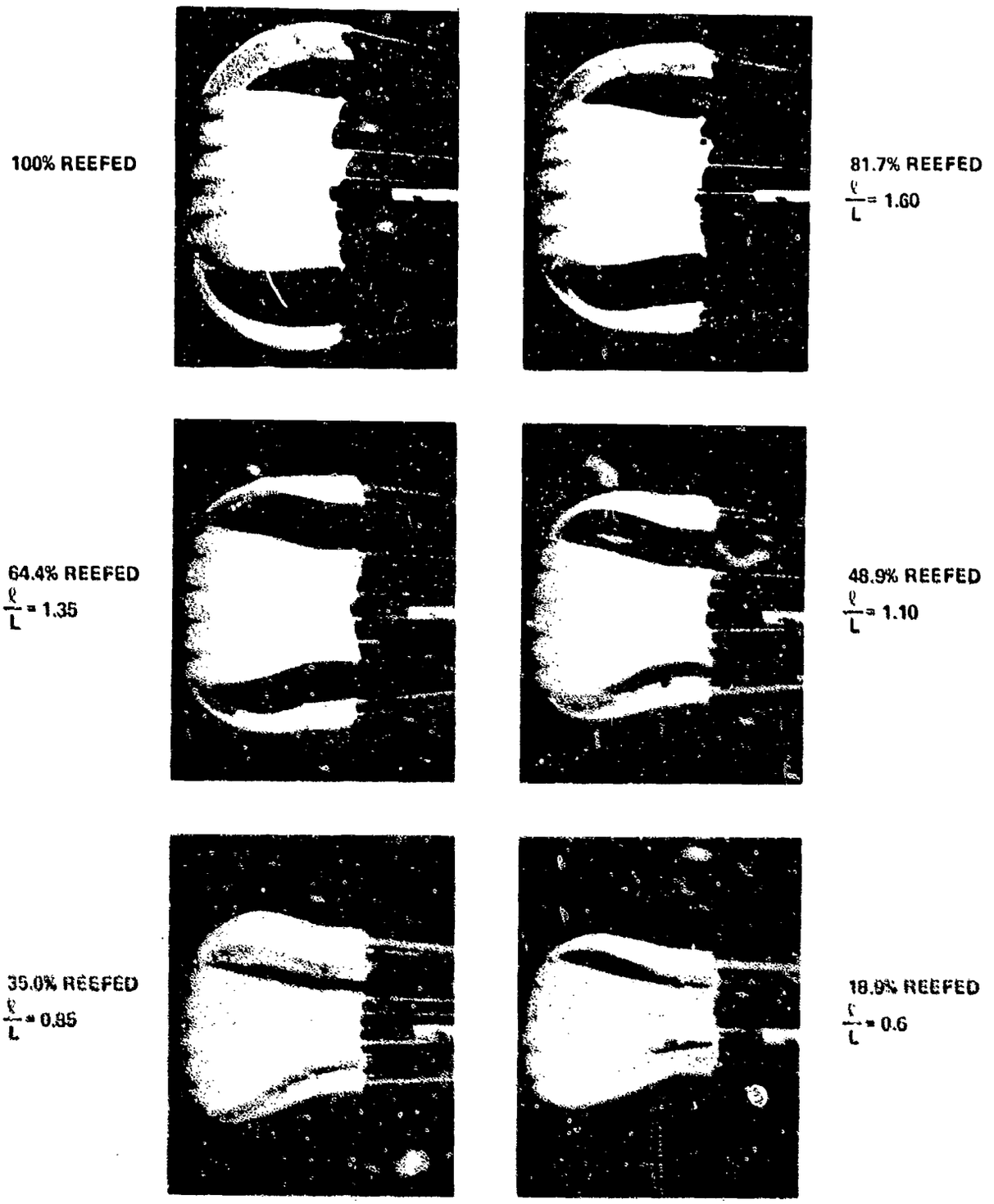


FIGURE 49 REEFED CANOPY INFLATED SHAPES; CLOTH PERMEABILITY = 351 CFM/FT^2; 24 SUSPENSION LINE PARACHUTE; SUSPENSION LINE LENGTH = 1.6 L; TEST VELOCITY = 293 FPS

TABLE 6 REEFING LINE FORCE TEST DATA TEST VELOCITY = 293 FPS

REEFING LINE LENGTH / CANOPY DIAMETER $\frac{\ell}{L}$	REEFING LINE FORCE / FULLY OPEN DRAG x 100								
	12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
	SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
CANOPY CLOTH PERMEABILITY = 98 CFM/FT^2									
1.60	1.13	2.21	2.59	1.45	2.66	3.14	2.58	3.86	3.87
1.35	2.76	3.92	4.27	2.76	3.81	4.29	3.70	4.41	4.63
1.10	3.44	4.20	4.34	3.28	3.95	3.91	3.77	4.00	4.06
0.85	3.14	3.11	3.40	3.18	3.31	3.21	3.26	3.15	3.24
0.60	2.12	1.73	1.98	2.32	2.30	2.36	2.47	2.30	2.29
CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2									
1.60	0.54	1.25	1.66	0.63	1.57	2.08	1.67	2.80	0.69
1.35	2.08	2.92	2.92	2.16	2.30	3.23	3.00	3.78	2.80
1.10	2.67	2.97	2.49	2.40	2.70	3.15	3.08	3.35	3.83
0.85	2.67	2.48	1.86	2.17	2.34	2.59	2.81	2.81	3.53
0.60	1.60	1.34	1.10	1.51	1.39	1.41	1.72	1.71	2.80
CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2									
1.60	0.79	0.79	1.08	0.18	2.02	1.49	0.68	1.74	1.99
1.35	1.95	–	2.04	1.31	2.39	2.66	1.95	2.91	2.72
1.10	1.76	1.45	2.09	1.92	2.51	2.44	2.29	2.40	2.52
0.85	1.48	0.98	1.27	1.86	1.94	1.90	1.93	2.87	2.04
0.60	1.23	–	0.49	0.97	1.01	0.83	0.83	1.30	1.03

TABLE 7 REEFING LINE FORCE 1σ TEST DATA VARIATION, TEST VELOCITY = 293 FPS

REEFING LINE LENGTH / CANOPY DIAMETER $\frac{\ell}{L}$	$\frac{1\sigma \text{ REEFING LINE FORCE}}{\text{FULLY OPEN DRAG}} \times 100$								
	12 SUSPENSION LINES			16 SUSPENSION LINES			24 SUSPENSION LINES		
	SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER			SUSPENSION LINE LENGTH / CANOPY DIAMETER		
	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L	1.0 L	1.4 L	1.6 L
CANOPY CLOTH PERMEABILITY = 98 CFM/FT^2									
1.60	0.22	0.19	0.18	0.21	0.17	0.21	0.28	0.25	0.19
1.35	0.22	0.21	0.18	0.20	0.16	0.22	0.30	0.27	0.22
1.10	0.25	0.24	0.23	0.22	0.19	0.30	0.27	0.24	0.22
0.85	0.28	0.22	0.32	0.20	0.19	0.18	0.21	0.18	0.21
0.60	0.27	0.25	0.18	0.18	0.24	0.20	0.24	0.21	0.21
CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2									
1.60	0.16	0.17	0.19	0.15	0.83	0.18	0.26	0.21	0.20
1.35	0.20	0.16	0.21	0.20	1.44	0.18	0.28	0.22	0.20
1.10	0.20	0.18	0.19	0.20	1.08	0.17	0.23	0.21	0.19
0.85	0.19	0.23	0.22	0.20	0.17	0.16	0.19	0.18	0.20
0.60	0.17	0.11	0.21	0.00	0.16	0.15	0.19	0.15	0.17
CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2									
1.60	0.18	0.20	0.17	0.08	0.23	0.21	0.18	0.20	0.19
1.35	0.24	0.16	0.20	0.20	0.27	0.22	0.23	0.21	0.19
1.10	0.21	0.18	0.19	0.21	0.25	0.17	0.22	0.19	0.15
0.85	0.14	0.14	0.11	0.18	0.22	0.14	0.18	0.16	0.14
0.60	0.55	0.12	0.10	0.11	0.14	0.09	0.11	0.11	0.09

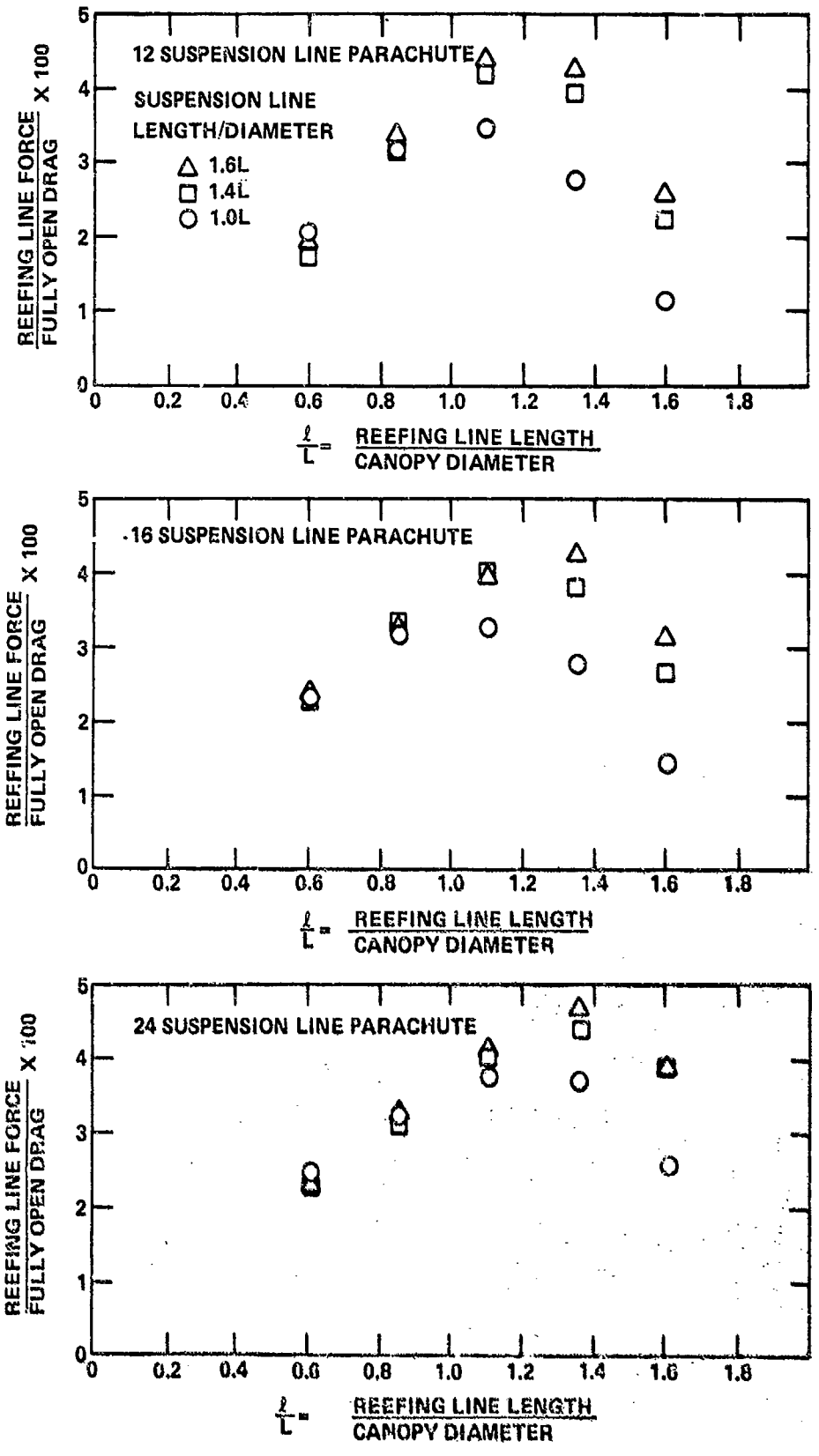


FIGURE 50 REEFING LINE FORCE TEST DATA CANOPY CLOTH PERMEABILITY = 98 CFM/FT^2 TEST VELOCITY = 293 FPS

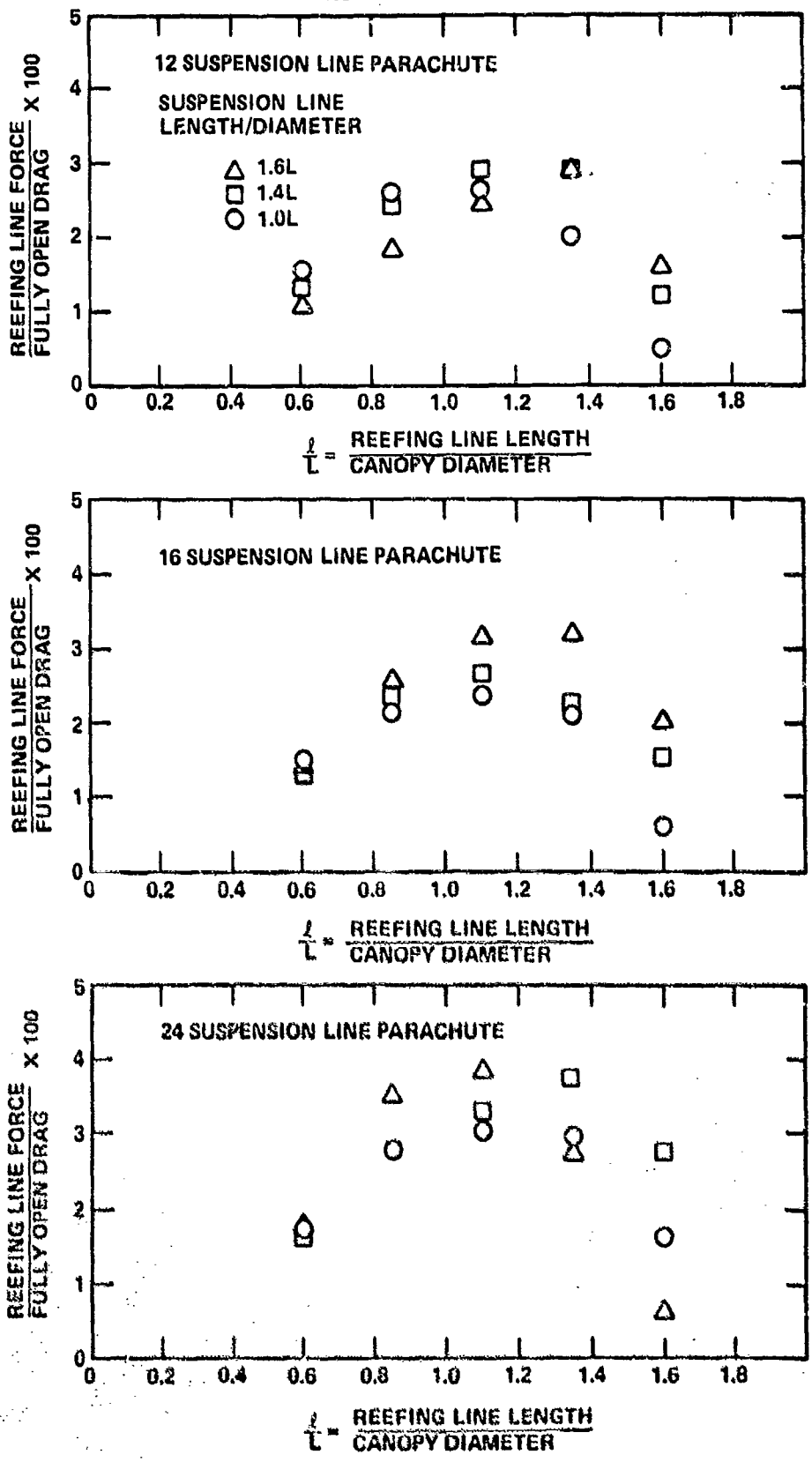


FIGURE 61 REEFING LINE FORCE TEST DATA CANOPY CLOTH PERMEABILITY = 225 CFM/FT^2 TEST VELOCITY = 283 FPS

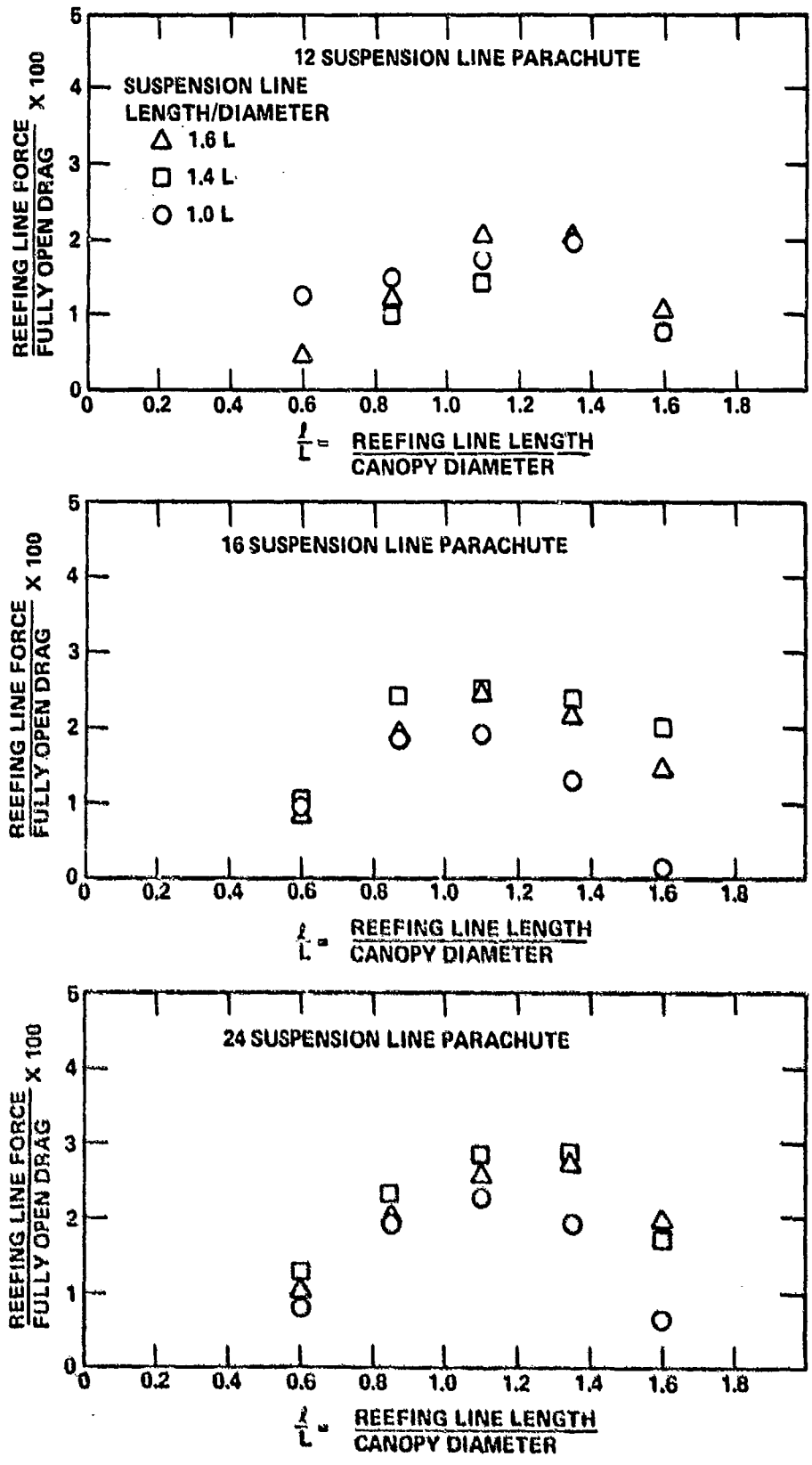


FIGURE 62 REEFING LINE FORCE TEST DATA CANOPY CLOTH PERMEABILITY = 351 CFM/FT^2 TEST VELOCITY = 293 FPS

TERMS

D	drag force, lbs
C_D	coefficient of drag
V	velocity, ft/sec
ρ	density of air, slugs/ft^3
q	dynamic pressure, lbs/ft^2
S_o	canopy reference area, ft^2
L	length of canopy arm
W	width of canopy arm
ℓ	length of reefing line
W/L	canopy arm width-to-length ratio
ℓ/L	reefing line length-to-canopy-diameter ratio
Permeability	rate of airflow through cloth in CFM/ft^2 when measured under a pressure differential of 1/2 inch of water
Reefing	a restriction of a drag producing surface to a diameter less than its diameter when it is fully inflated.
Percent Reefed	ratio of the drag force produced in the reefed condition to the drag force of the fully inflated parachute at the same velocity x 100.
Percent Reefing Line Load	ratio of force in the reefing line in the reefed condition to the drag force of the fully inflated parachute at the same velocity x 100.

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